Ground Motion Studies

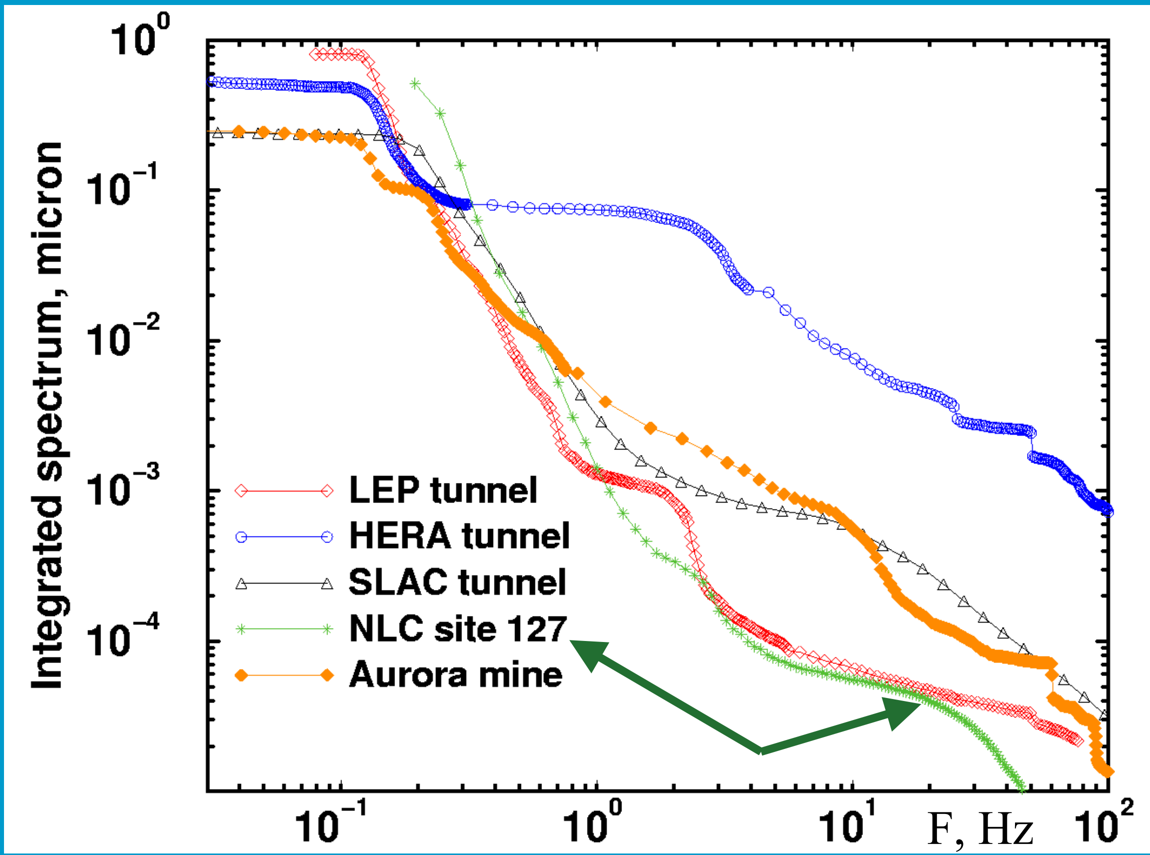
Andrei Seryi
SLAC

MAC meeting, FNAL
May 9-11, 2002

Contents:

- Natural motion, near noises, vibration propagation
  - Representative sites study
  - NUMI tunnel study (FNAL, Northwestern, BNL, BINP, SLAC)
  - Two tunnels study proposal
  - Slow motion study at FNAL and SLAC
- On girder vibration caused by cooling
  - Accelerating structure vibration, linac quad vibration, structure to quad vibration coupling
- FD noise, SLD 1995 measurements
- Summary

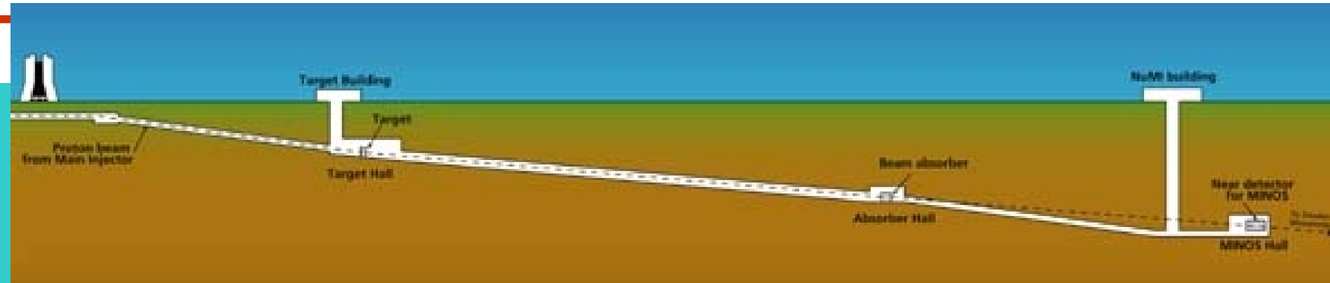
Ground motion at diff. sites



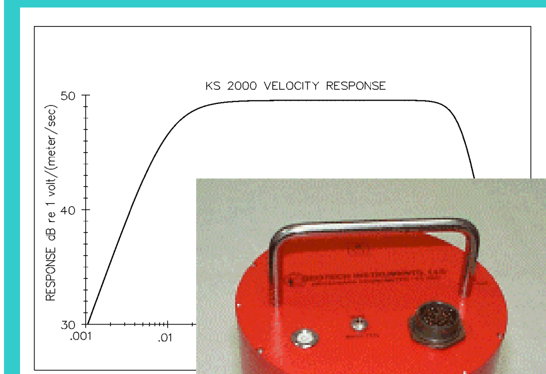
- NLC site 127 shows very low ground motion (on surface!)
- As good as at LEP
- No cultural noises (yet)
- Aurora mine is as quiet as SLAC site (may be impacted by in-mine noises)

Preparing ground motion study in NUMI

noise versus depth



Equipment ordered by NU



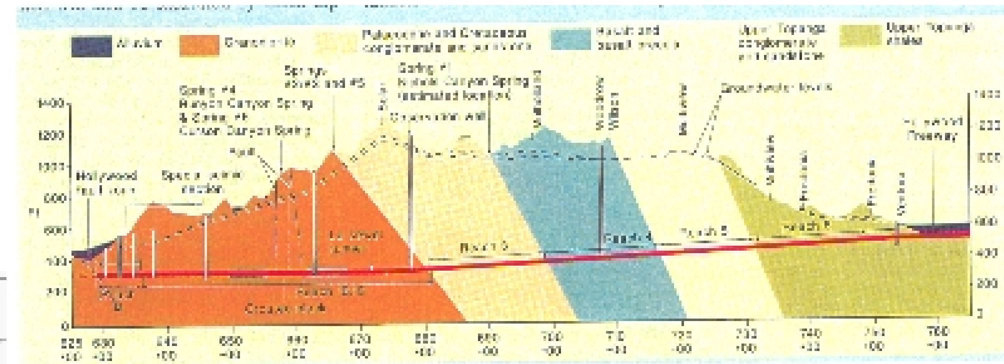
Broadband Three-component Seismometers KS-2000

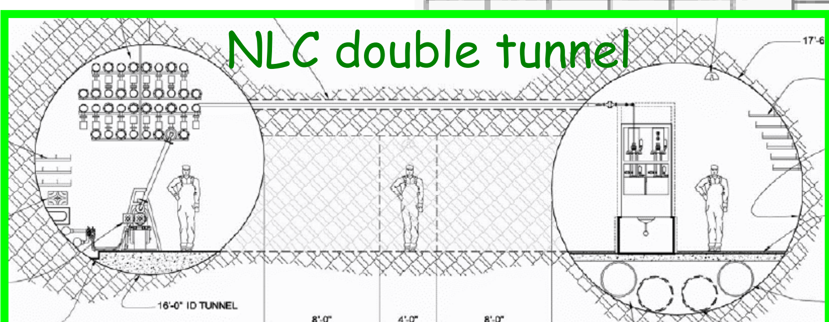
Portable Data Recorder DL-24

- Northwestern University joined the study, is providing equipment and will participate in the study
- Brookhaven colleagues agreed to help with vibration propagation analysis using codes they developed
- Hope that BINP colleagues could join and bring in their experience
- First study may happen at target area, next steps – depending on accessibility…

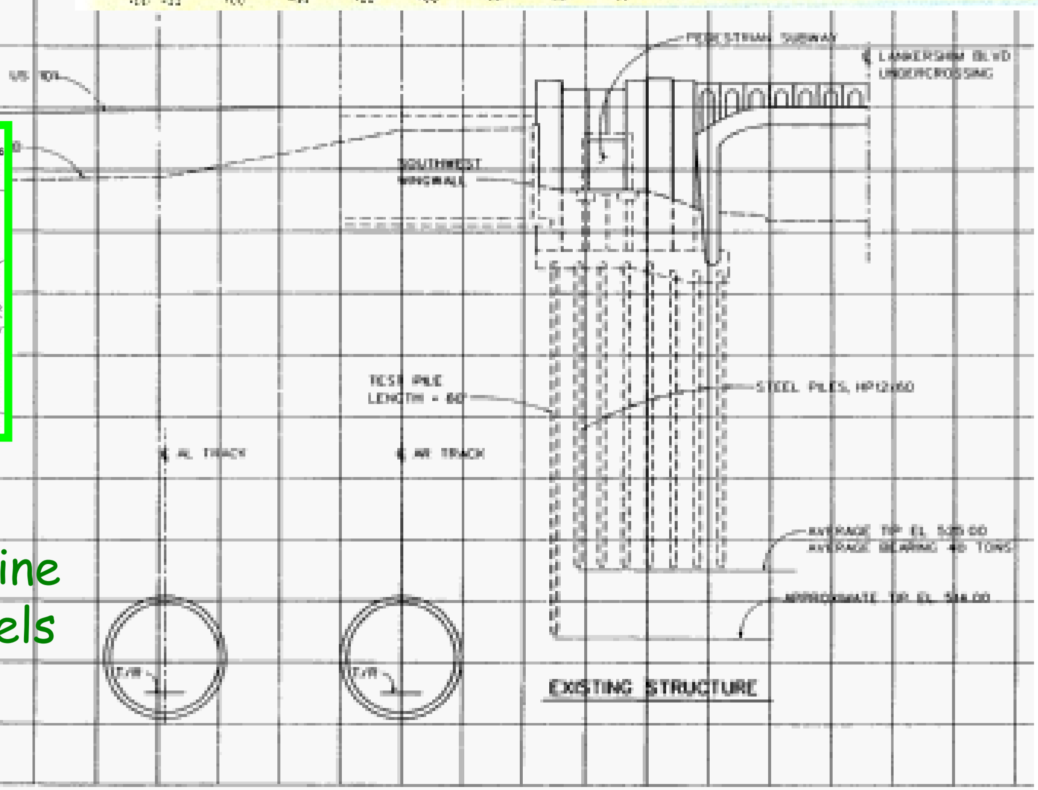
Discussing proposal to study vibration coupling in NLC-like two parallel tunnels

- **Goal**: study vibration transmission from utility tunnel to the main tunnel
- **Location**: metro tunnels from Hollywood Blvd. To Universal City
- **Proposed by:** DMJM and Colin Gorden & Associates (CG &A)





NLC double tunnel



metro Red line double tunnels

For more details see the talk of **Fred Asiri** at NLC collab. Mtg. May 2002

'Slow' Ground motion at NLC

- **Some data for diffusive or ATL motion:** $\Delta X^2 \sim A_D T L$ (min.-month)
  (T – elapsed time, L – separation between two points)

Place	A $\mu m^2/(m \cdot s)$
HERA R.Brinkmann,et al.	$\sim 10^{-5}$
FNAL surface * V.Shiltsev,et al.	$(1-10)*10^{-6}$
SLAC*	$\sim 5*10^{-7}$
Aurora mine* V.Shiltsev,et al.	$(2-20)*10^{-7}$
Sazare mine S.Takeda,et al.	$\sim 5*10^{-8}$

*** Further measurements in Aurora mine, SLAC & FNAL are ongoing**

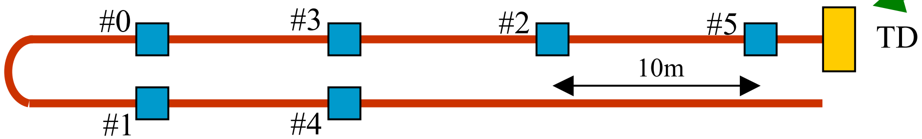
BINP - FNAL - SLAC
joint slow motion studies

- Measurements of slow ground motion in **three geologically different places**:
  - SLAC at the surface **(sandstone)**
    - New HLS (30m, 6sensors) installed in Sect.10 lab in Dec.2001
  - FNAL at the surface **(glacial till)**
    - New HLS (300m, 20sensors) installed in MI8 in Oct.2001
  - Aurora deep tunnel **(dolomite)**
    - New HLS will be installed in May 2002
- **Budker INP** developed new **Hydrostatic Level System** (HLS) sensors for these measurements
  - Overcame commercially available sensors
- First results discussed at collaboration meeting on May 7-8

BINP HLS @ sect.10

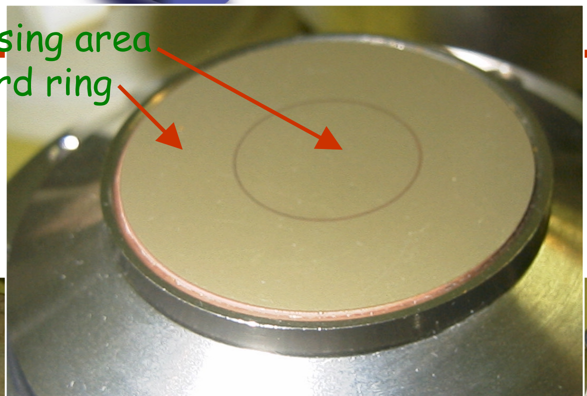
Dr. A.Chupyra (BINP)

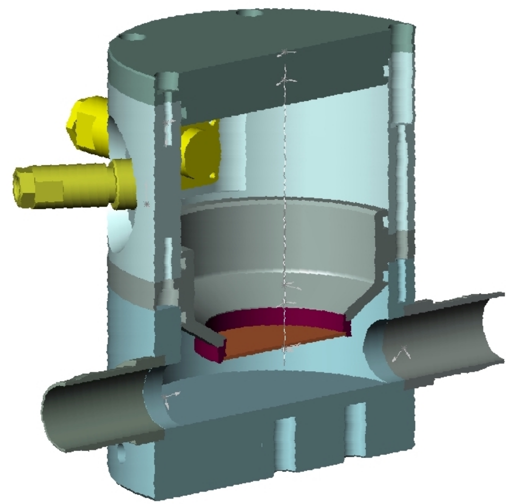
Test device



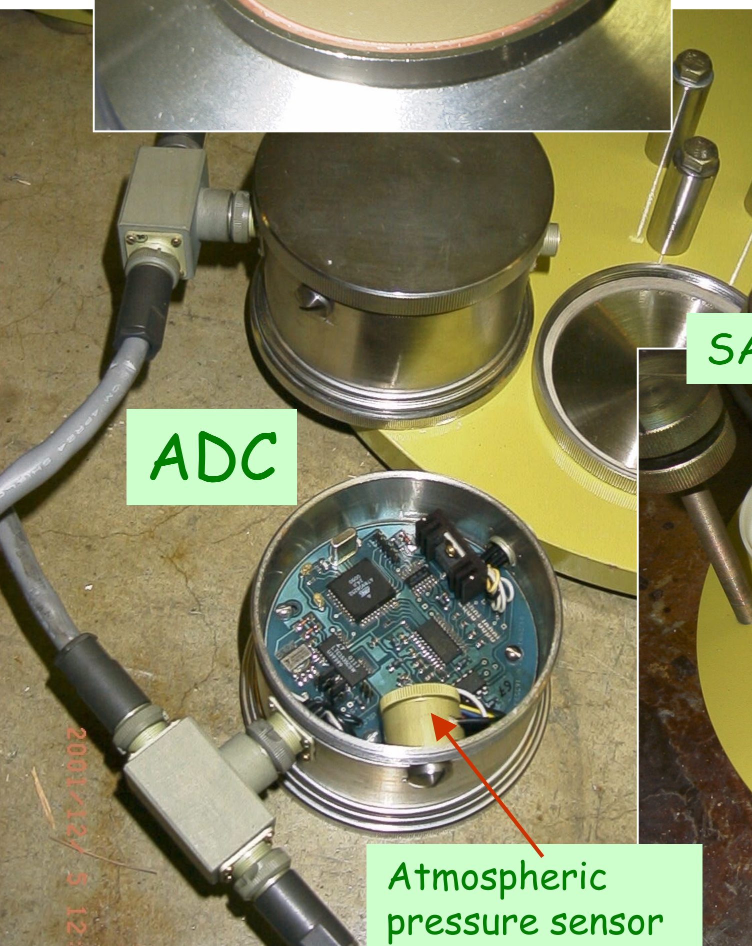
Two pairs of sensors installed close together to cross-check

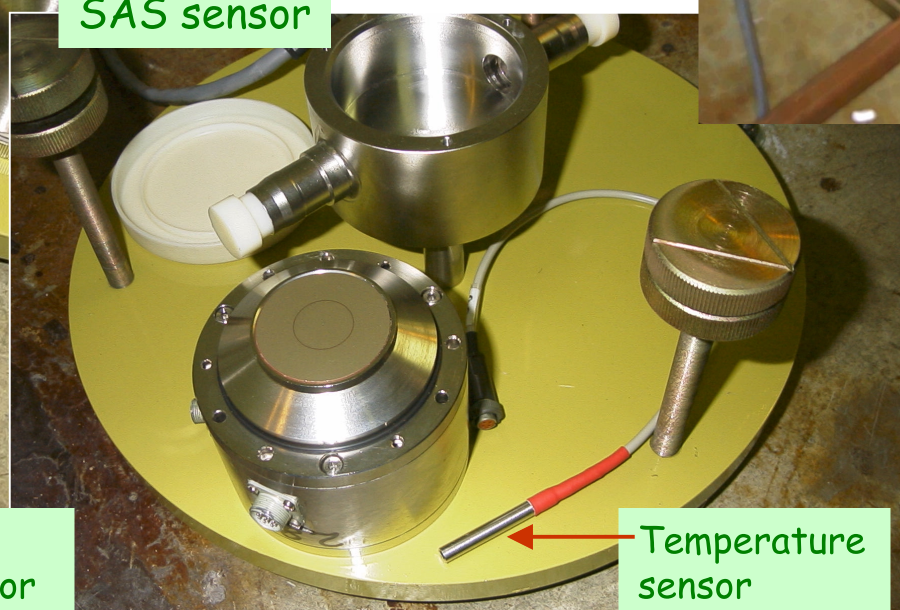
BINP HLS


Sensing area
Guard ring




Test device can
change level in
controlled way


ADC
Atmospheric
pressure sensor


SAS sensor
Temperature
sensor

Performance of HLS sensors

- Resolution ~50nm

- Sensors located together (e.g.0&1) follow each other within several microns for 4 months

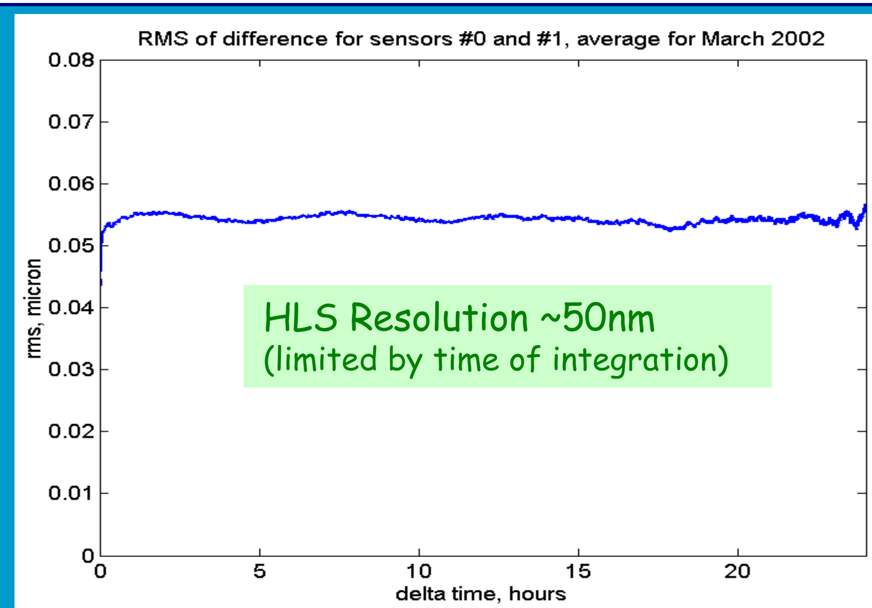
  (within ~1micron if compensated for T°)

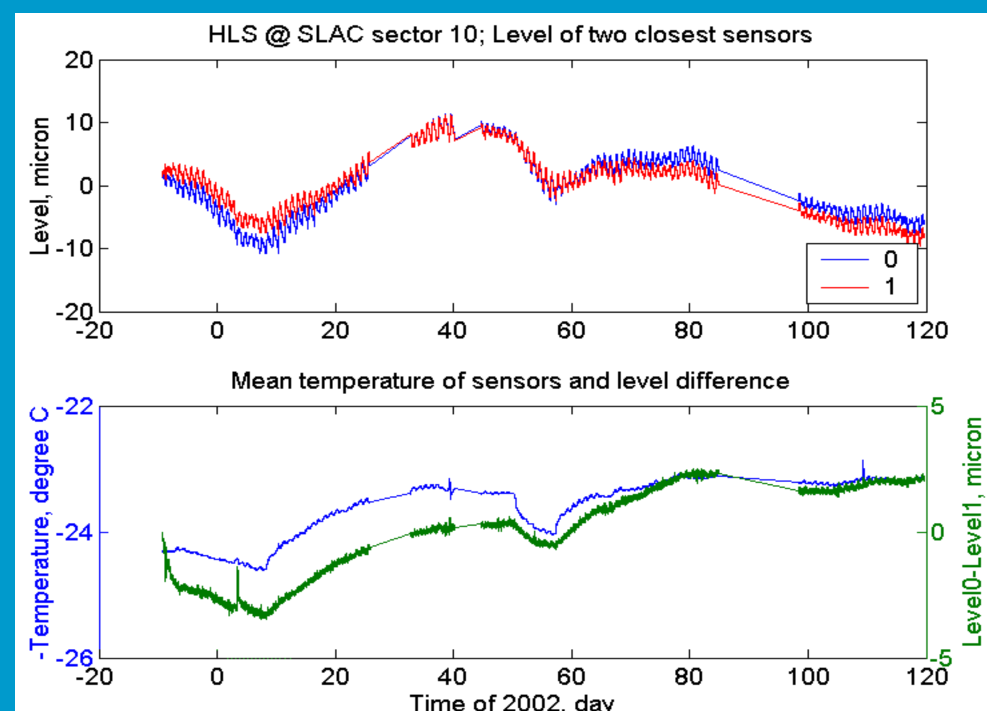
- Performance better than for known commercial HLS

- Meet our expectations as a tool for slow motion study

  Dynamics of water in pipes need to be taken into account

- Such HLS would also be suitable as monitoring tool for modern accelerators and Å light sources

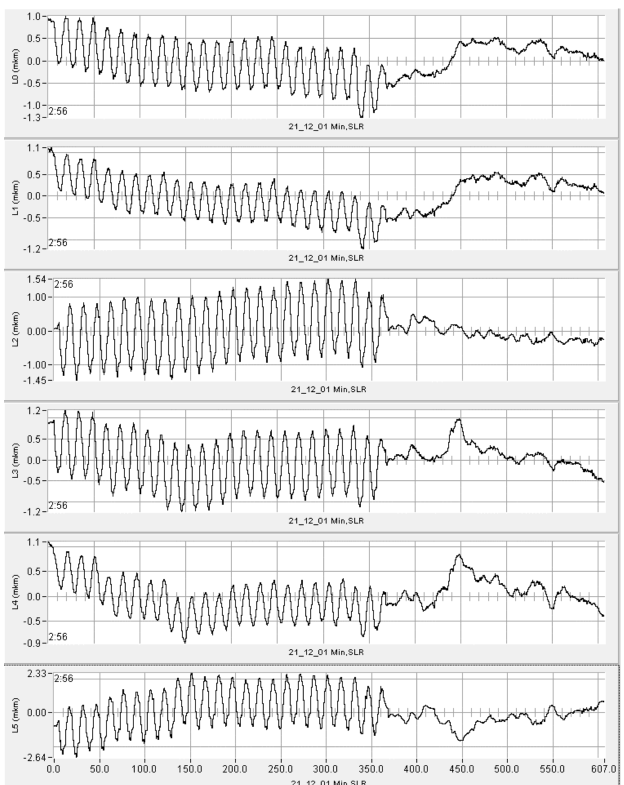


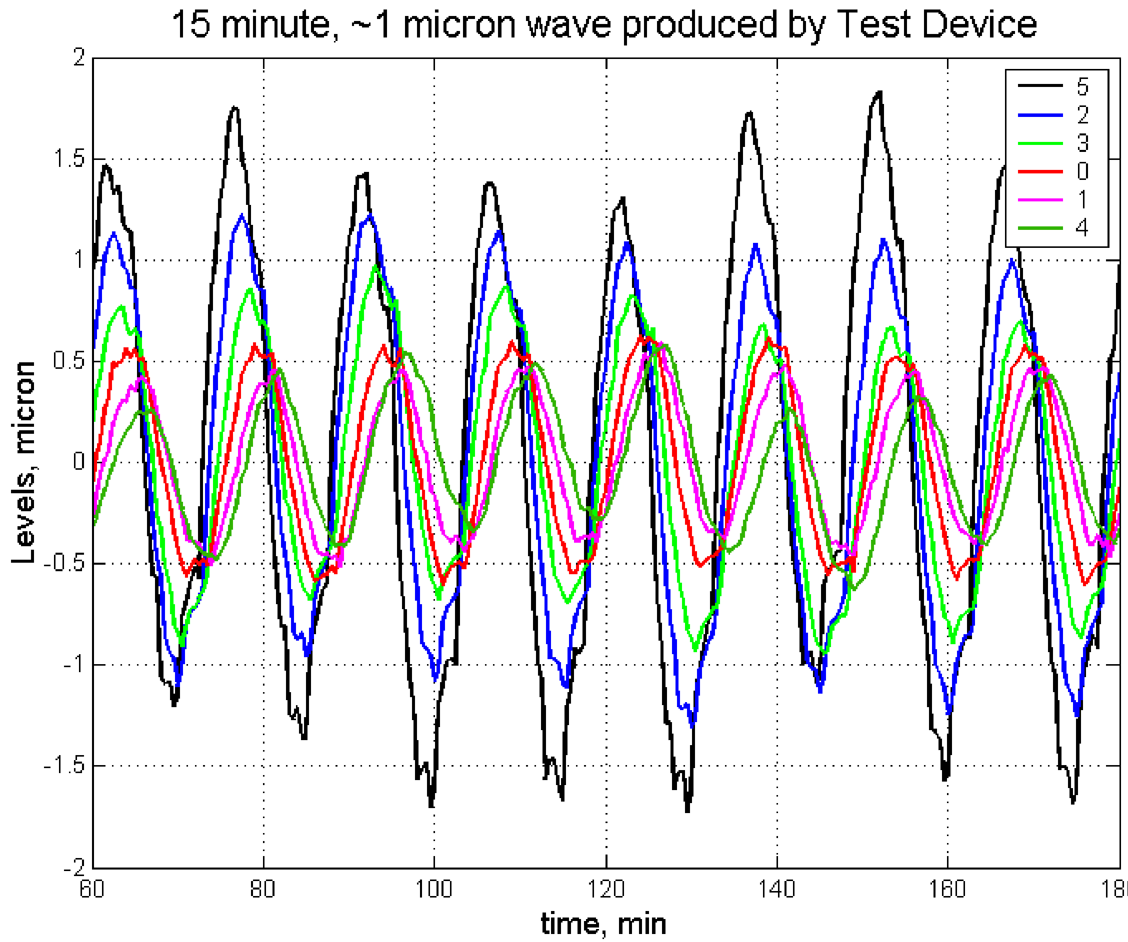


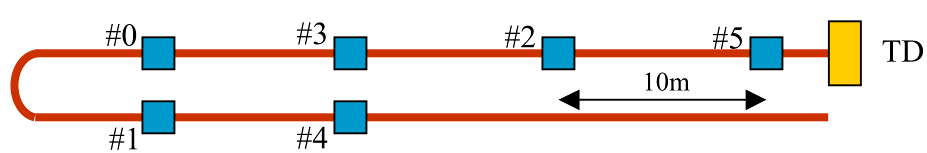
(Hydro) dynamics in the HLS pipes

One micron "wave" produced by Test device

Note delay and amplitude decrease to farther sensors







Analysis of HLS results is ongoing

snapshot of the work

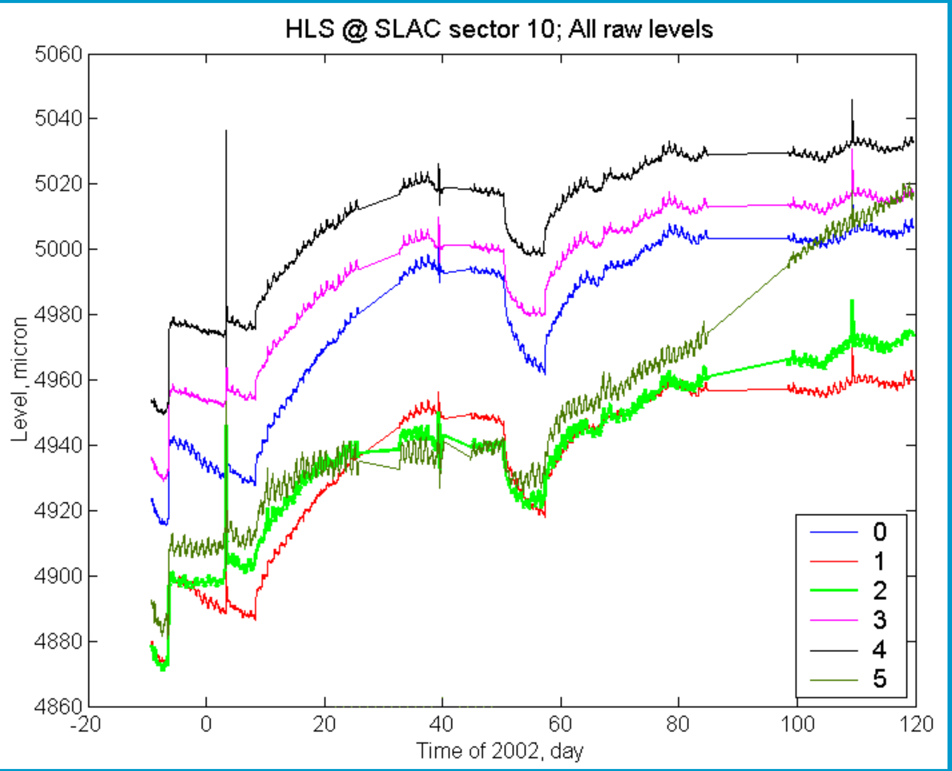
- Currently, relative motion at Sector 10 are dominated by tidal motion (change of overall slope without local deformation)

- Delay in the pipe, and probably friction, complicates complete removal of tides

  Looking for a solution

  Also, small reconfiguration of the HLS is required=>June

- Even though, preliminary analysis show that residual motion do not exceed and likely to be much smaller than tolerable

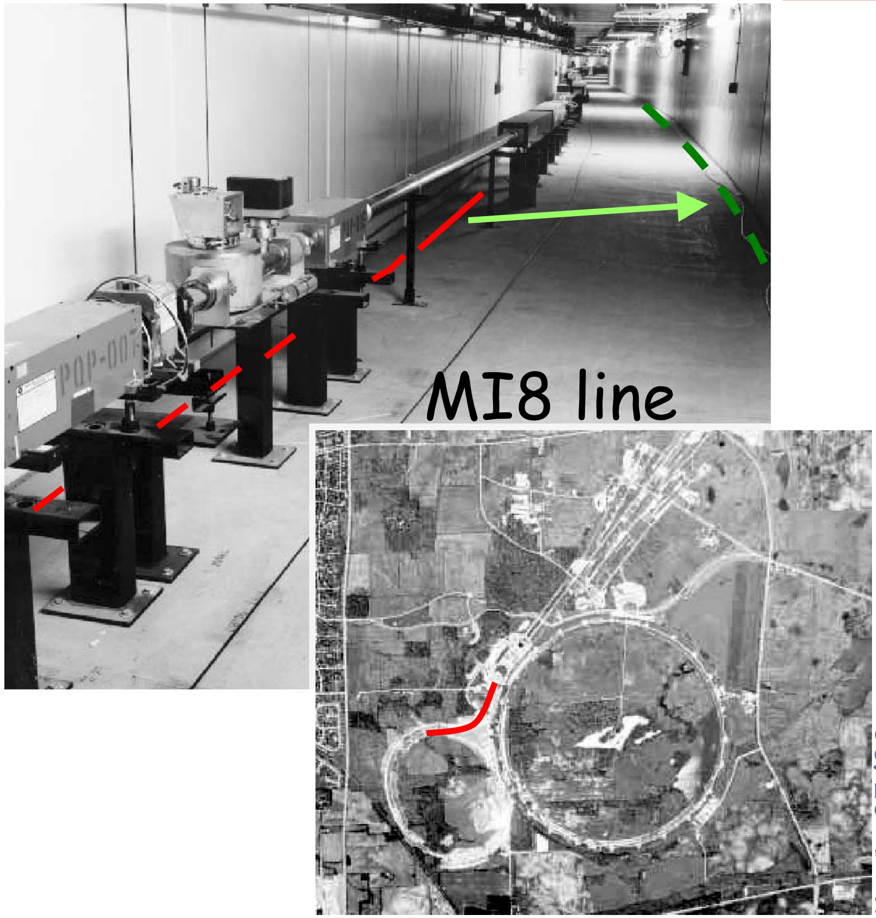


All levels, temperature compensation OFF

Note much larger tides in sensor #5, enhanced by water contained in the test device.

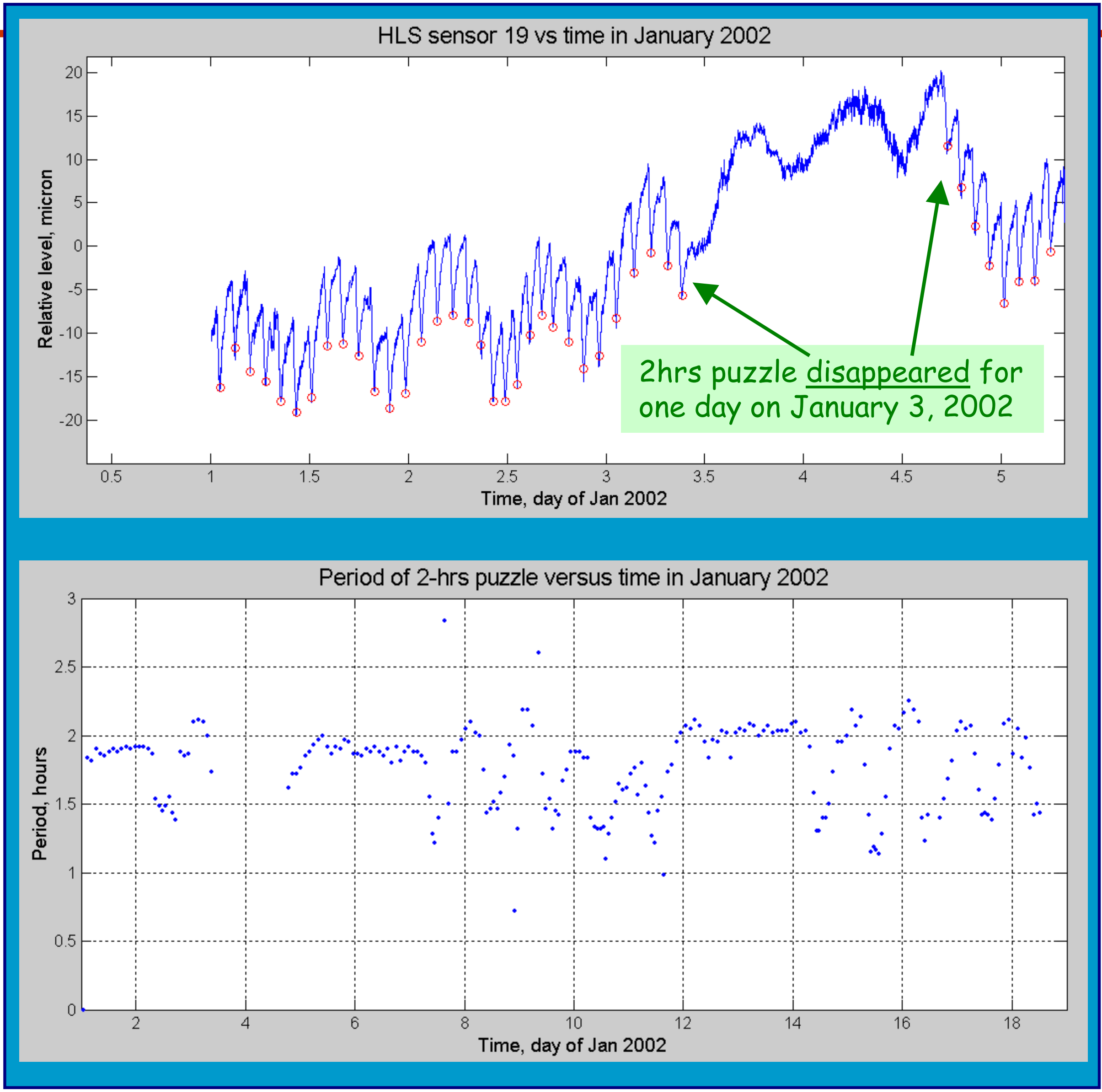
Slow motion studies at MI8

- HLS installed in MI8 in Oct.2001 on ~300m with
    - Started in Oct.2001
    - Planning reconfiguration to reduce radiation load on HLS (will move HLS to outer wall)



Cultural effects on slow motion

MI8 results



- Major component to relative motion at MI8 is given by "2hour puzzle" – 10 μm motion occurring near one of the end of the system
- Period change in time, looks like air-conditioning system
- Not easy to trace the source
- The motion seem to be real. Large amplitude, rather short period, bad correlation – potentially quite nasty for collider
- Cultural effects may influence slow motion too !

A.Seryi, NLC MAC, 05/02

Cultural noise at linac girder

- Linac girder should meet the stability requirements
  - Vibration, long term position, temperature stability, and other requirements

- FNAL and SLAC together need to pursue R&D program to clarify the requirements, identify potential issues and find directions of design optimization
  - Long term position stability
  - Vibration-optimized design

    Hopefully, will be done at FNAL, addressing full length girder
  - Vibration stability R&D
    - Cooling water induced vibrations
      - In RF structure due to **cooling**
      - In linac quad (if EM) due to **cooling**
      - In linac quad due to **coupling** to RF structure

      Currently being studied at SLAC with existing **2m** girder

* Here "Linac girder" actually means the girder itself with RF structure, quadrupole, movers, etc., i.e. it is a piece of the linac with all stuff involved.

NLC RF Structure vibration

- Dissipating heat caused by RF power:
  => need large flow of cooling water
  => this cause vibrations

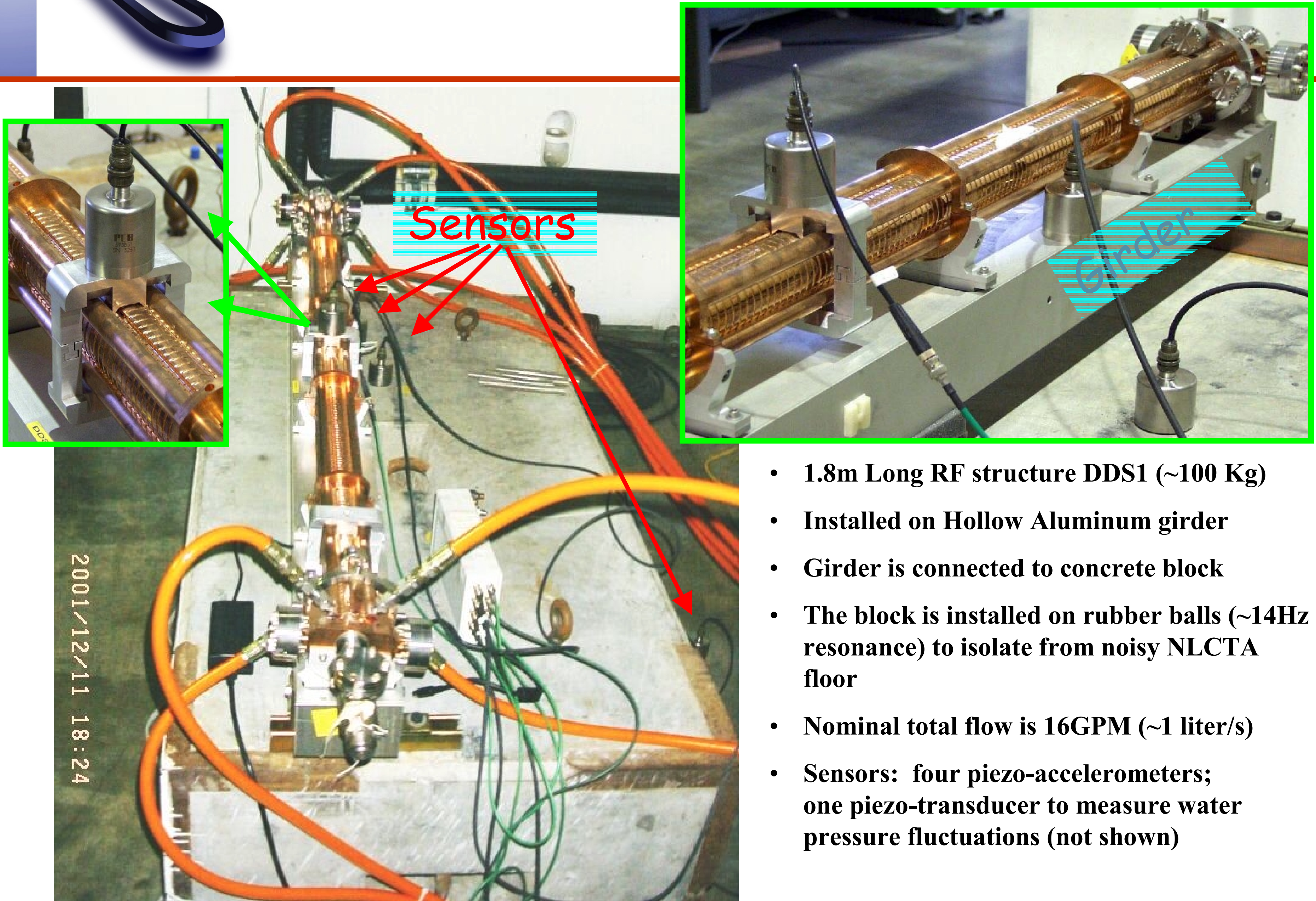
For more details
see the talk of
Frederic Le Pimpec
at NLC collab. mtg. May 2002

  - Tolerances for structure vibration are rather loose (μm scale)

  - **More worrisome issue:**
    - **vibration coupling, even tiny, from RF structure to a quadrupole* (nm tolerance)**

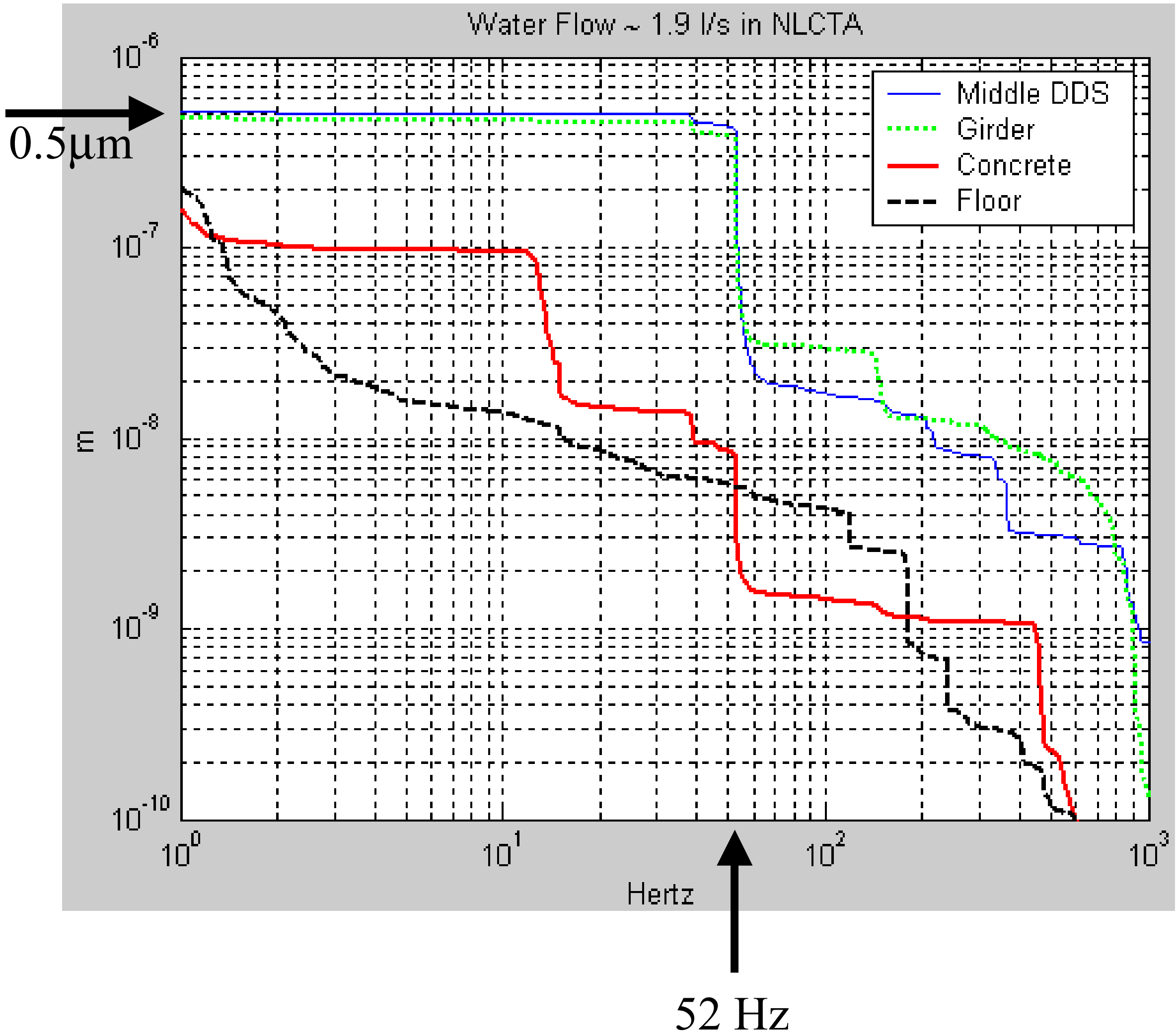
* RF structure is connected to a quad via vacuum pipe and BPM which has to be attached to a quad (to provide BPM to quad position stability). The quadrupole and structure are separated by a bellow. The bellow decouples most of longitudinal and transverse motion, but not the torque.

Structure vibration tests at NLCTA



- 1.8m Long RF structure DDS1 (~100 Kg)
- Installed on Hollow Aluminum girder
- Girder is connected to concrete block
- The block is installed on rubber balls (~14Hz resonance) to isolate from noisy NLCTA floor
- Nominal total flow is 16GPM (~1 liter/s)
- Sensors: four piezo-accelerometers; one piezo-transducer to measure water pressure fluctuations (not shown)

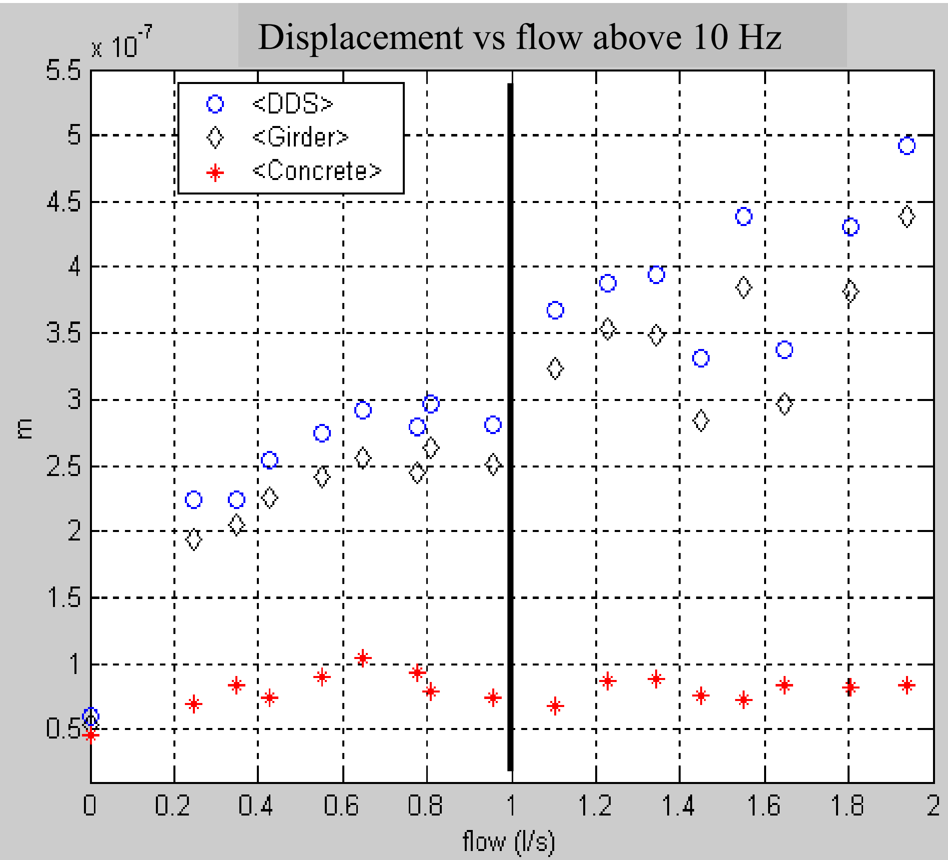
First results on cooling water induced vibration of RF structure at 1.9 l/s

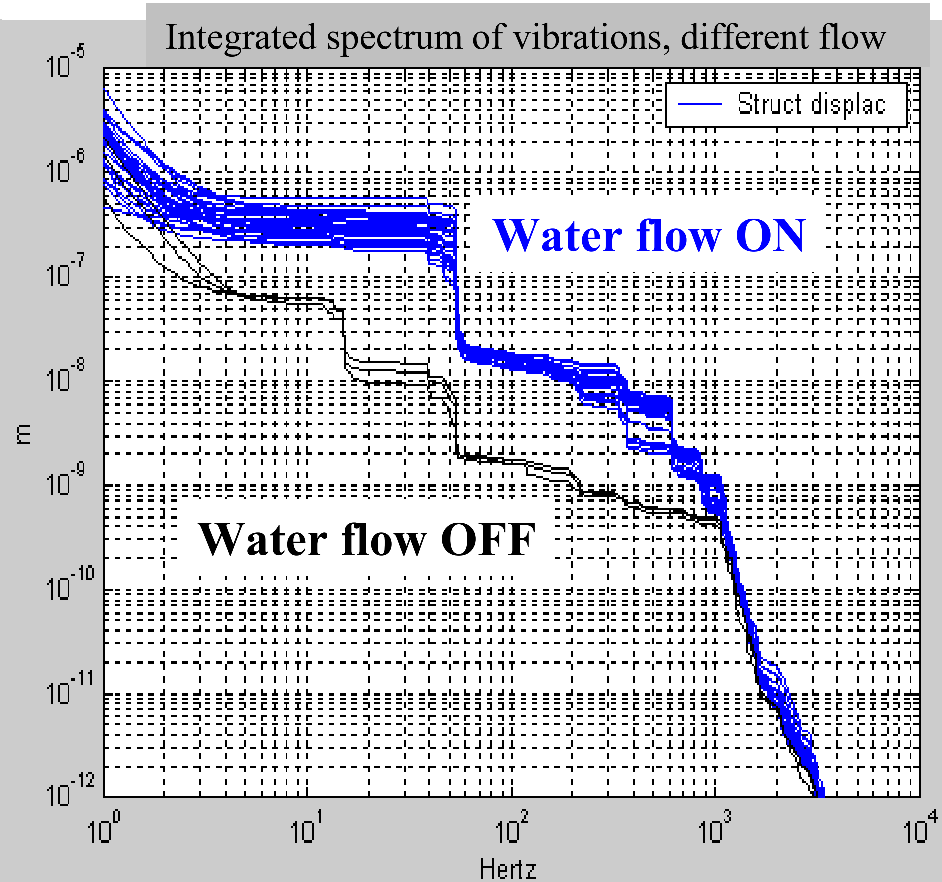


- RF structure vibration is ~0.5μm
- Most of amplitude comes from the peak at ~52Hz

  (corresponded to a resonance of the girder – more discussion below in the talk)

Vibration of RF structure versus water flow



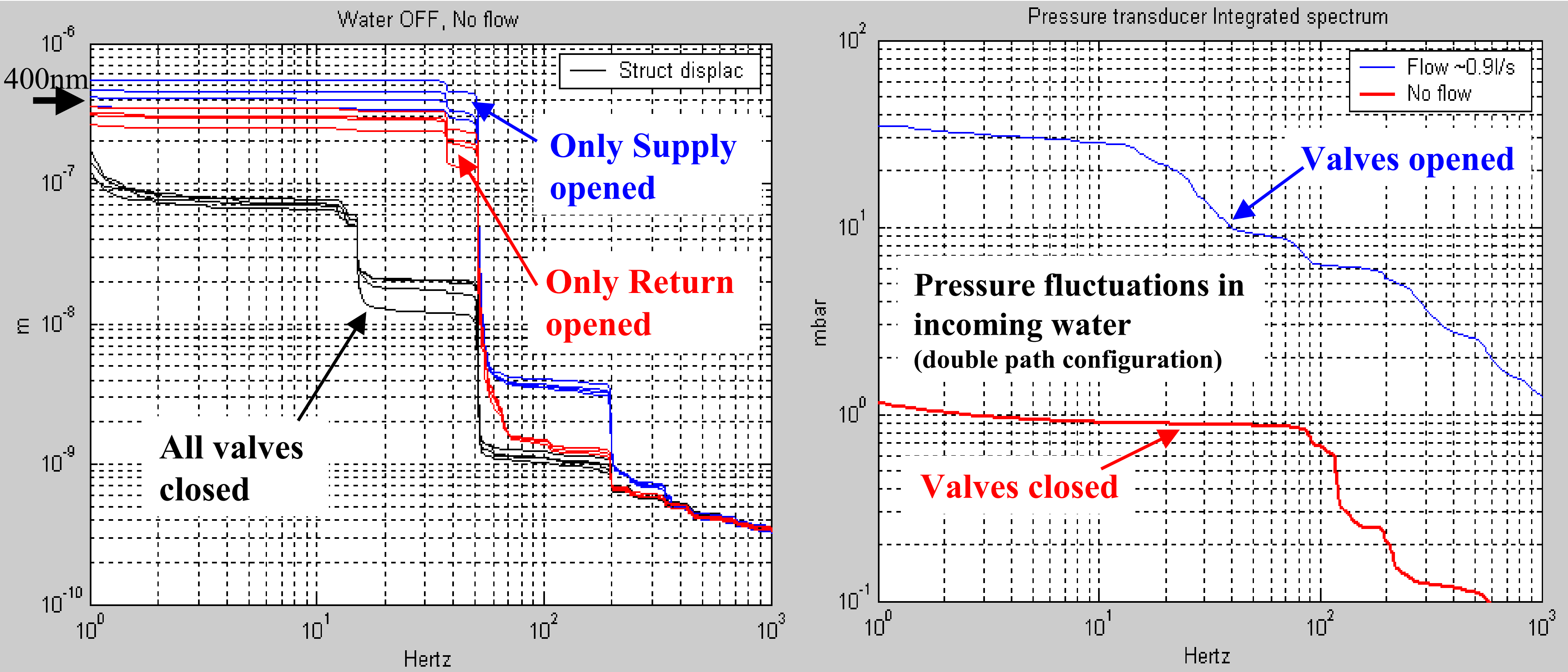


- Vibration depends only smoothly on the flow rate
- Flow changes 10 times , but vibration only 2 times

Our findings change approach to an optimal design

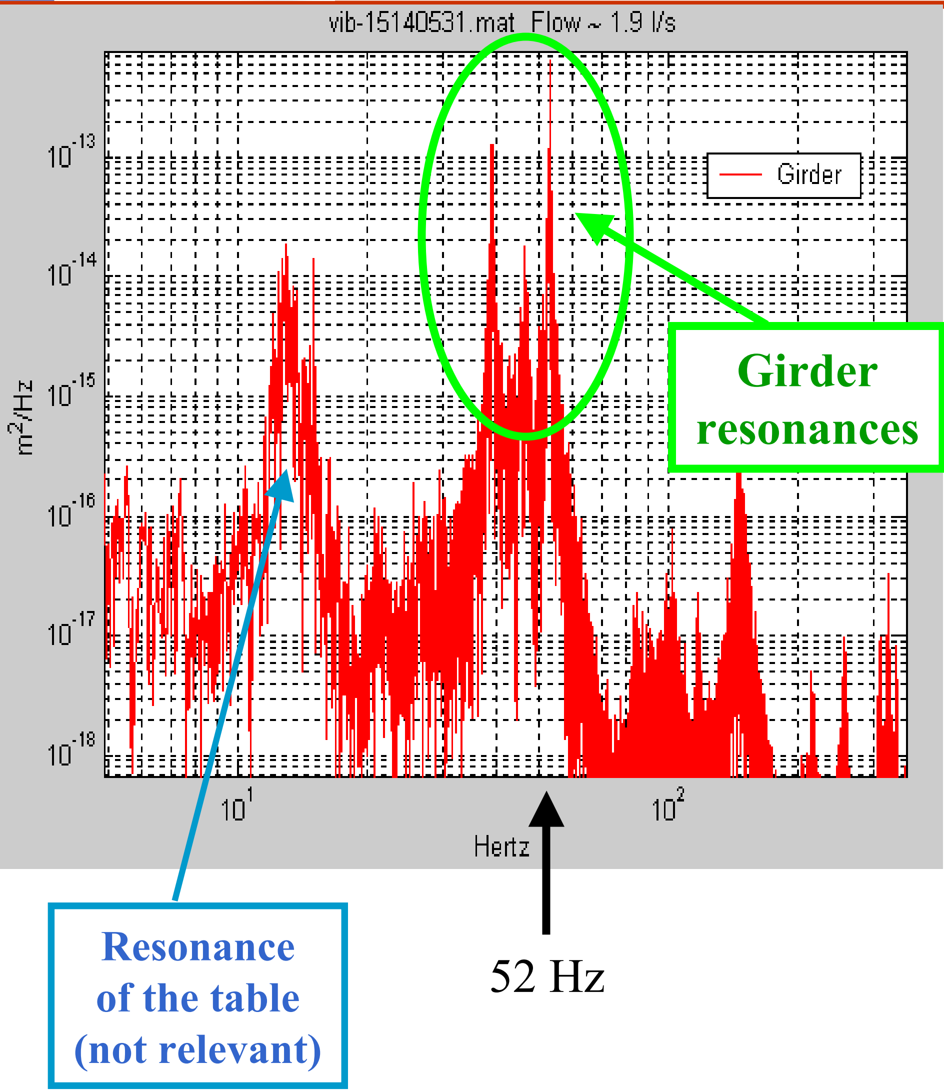
- Before starting this study, there was a **general belief** that **to reduce "flow induced vibration"** one might **decrease the flow rate**
- **We found that this is not always true**
- Vibration almost **does not or slowly depend on flow** because its large fraction is **cased not by turbulence inside the structure or quadrupole, but by turbulence in water supplying system**
- Merely opening **only Supply** valve would produce almost the same vibration

RF structure vibration without flow, caused by pressure fluctuations in incoming water



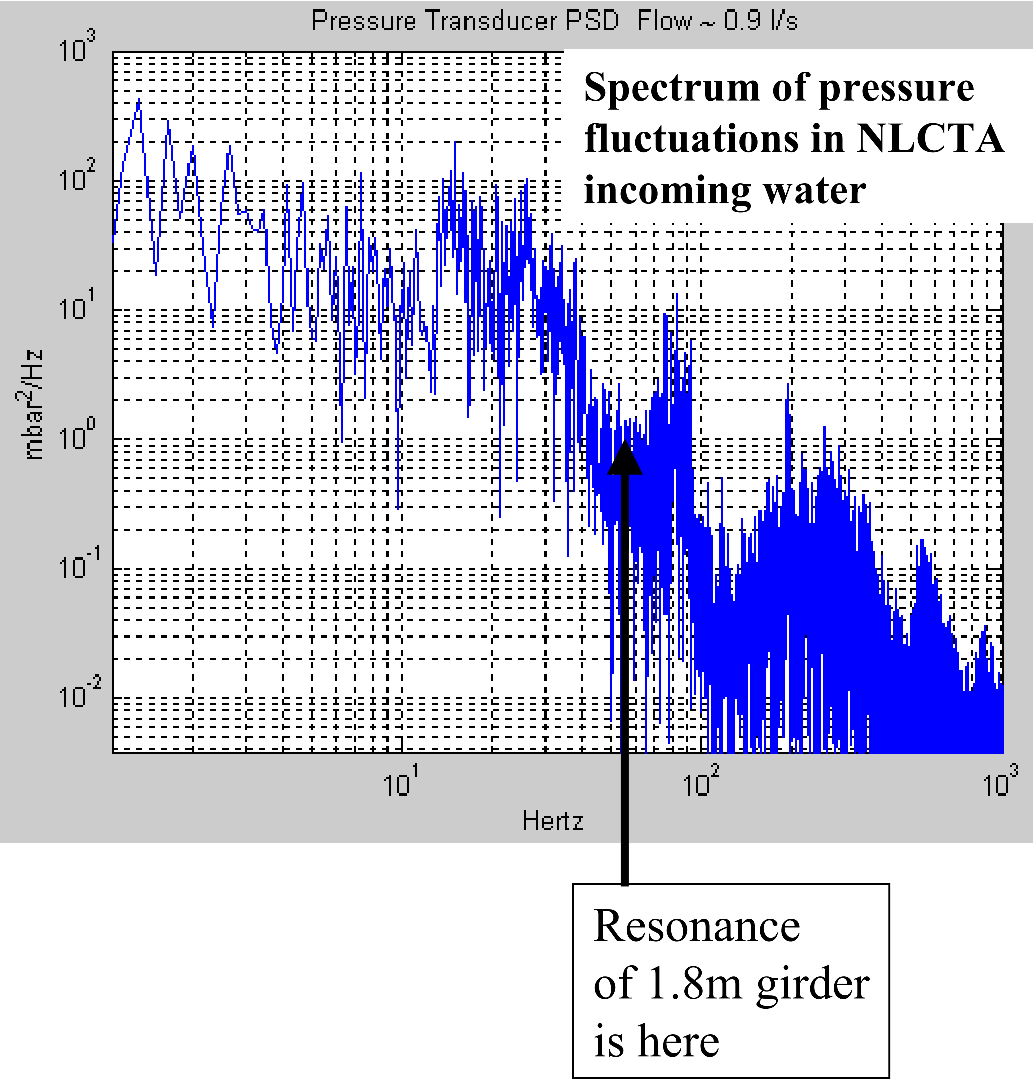
Most of vibration is caused not by turbulence in RF structure itself, but by pressure fluctuations in incoming water, I.e. by turbulence in largest supplying pipes

Mechanical resonances greatly increase girder vibrations



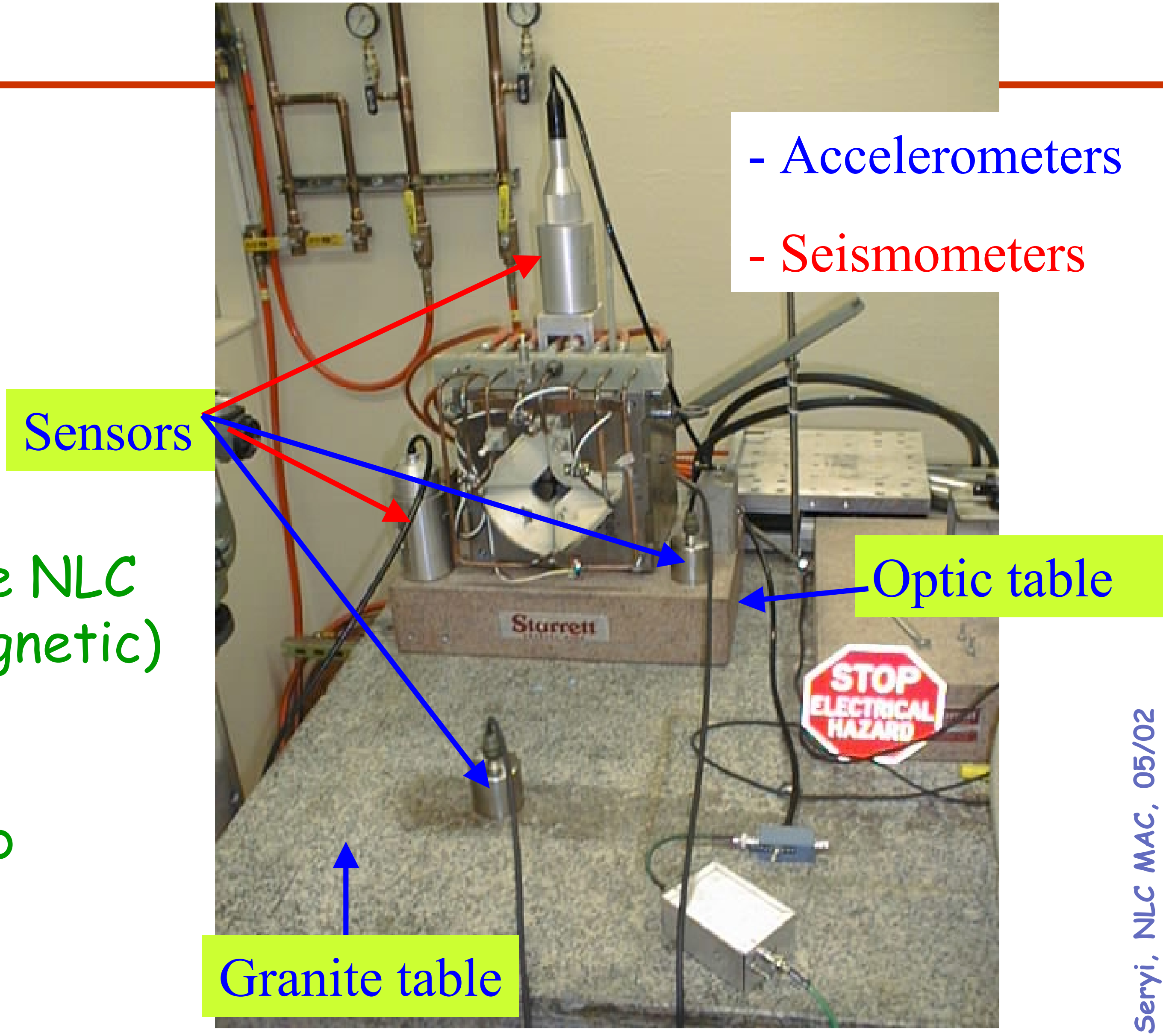
- RF structure vibration is driven by **pressure fluctuation in incoming water**
- Girder **resonances** enhance vibration (main one at 52 Hz)
- Resonance frequency scales as $1/L^2$ => full length girder of similar design may have much lower resonance F
  (this is a concern)

Why low resonance frequency of a girder is a concern



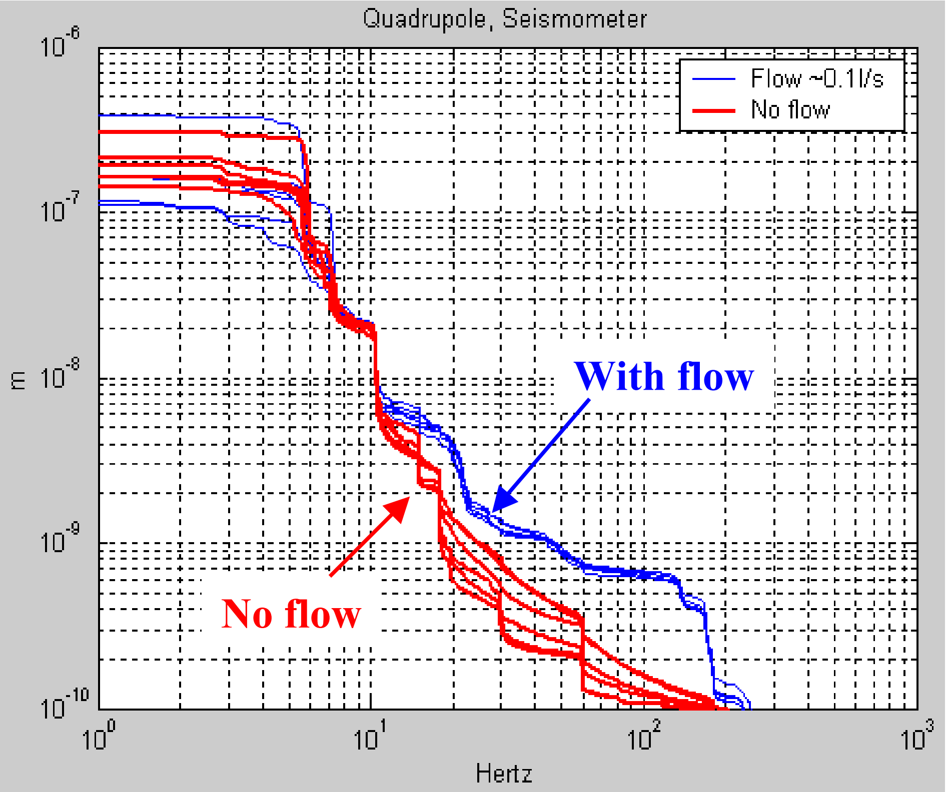
- Driving forces (ground motion, pressure ΔP/P, ...) always higher at lower freq.
- The full length girder should be designed so that damping is increased and low F resonances avoided
- The cooling water supplying system may need to be made more quiet
  => need to study what is feasible?

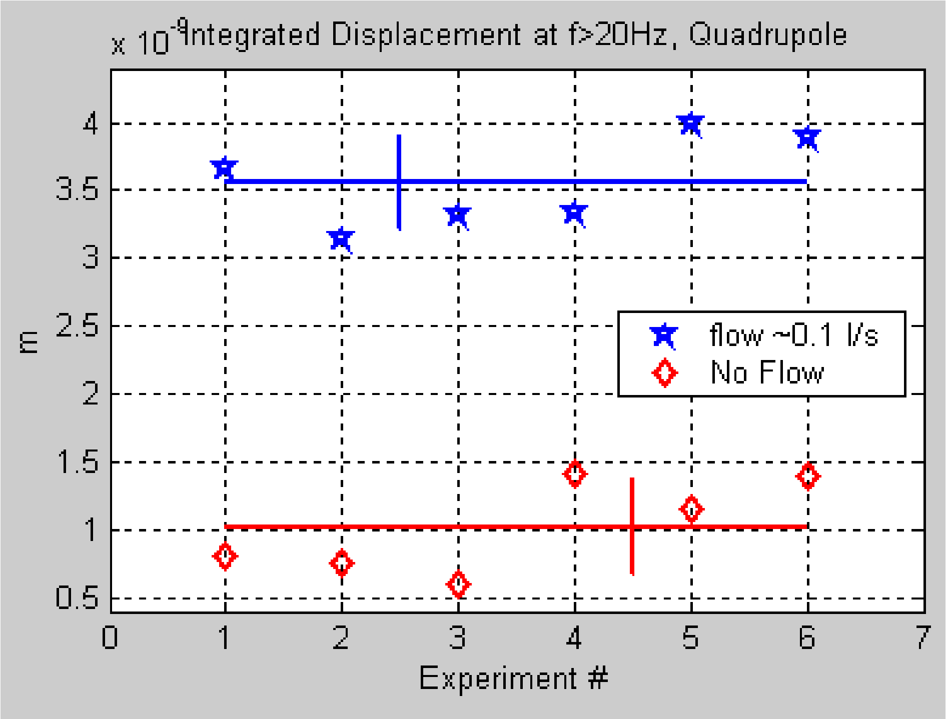
Water induced vibration in NLC EM Quad



Prototype of the NLC **EM** (Electro Magnetic) quad installed in magnetic measurement lab

EM quad vibration with cooling water





- EM quad vibrates ~**3.35nm*** for **F>20Hz** due to cooling

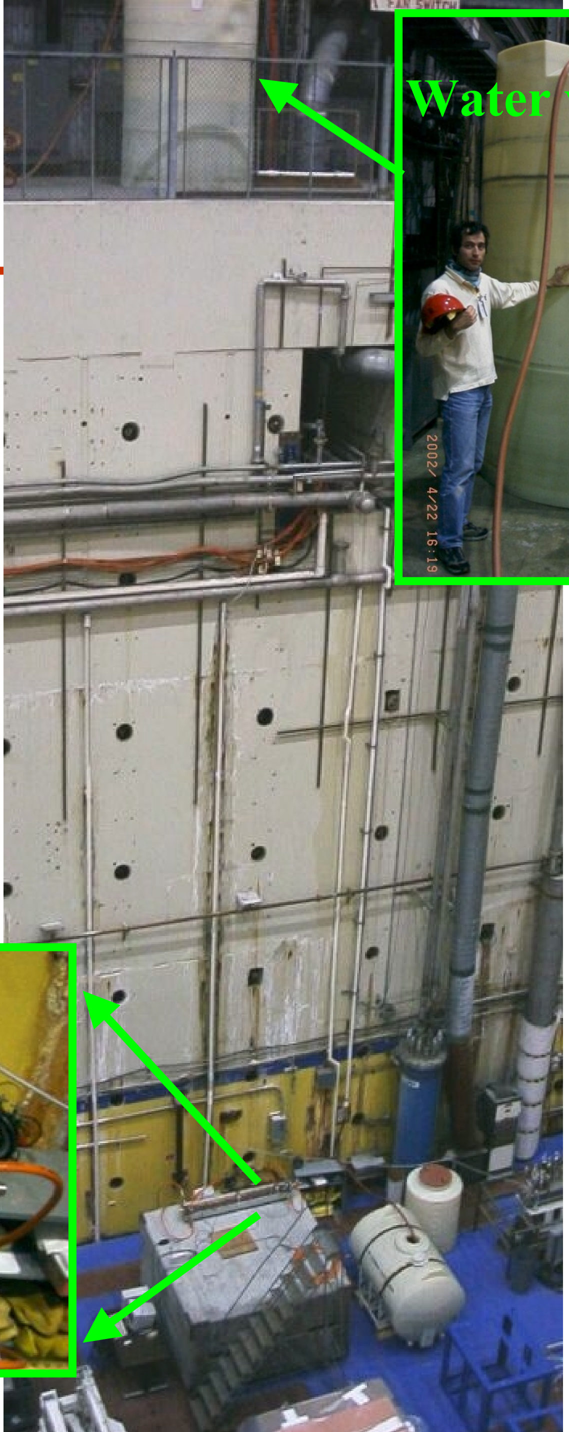
Measurements for frequency lower than 10Hz are not possible in magnetic lab because of high ambient vibration

* Assuming additional vibration is uncorrelated : $(3.5^2 - 1)^{\frac{1}{2}} = 3.35$nm

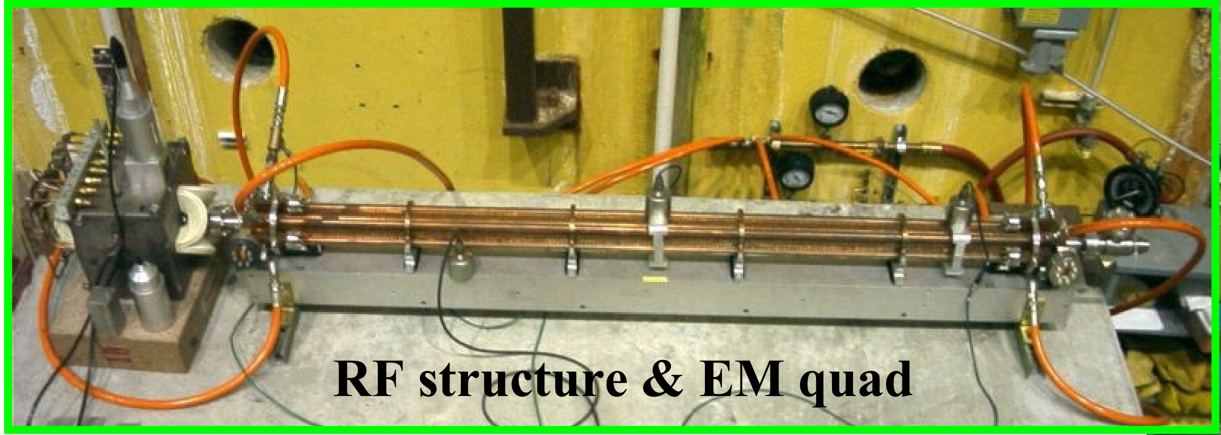
Gravity fed studies

- Study vibration of the girder with gravity-fed “quiet” water

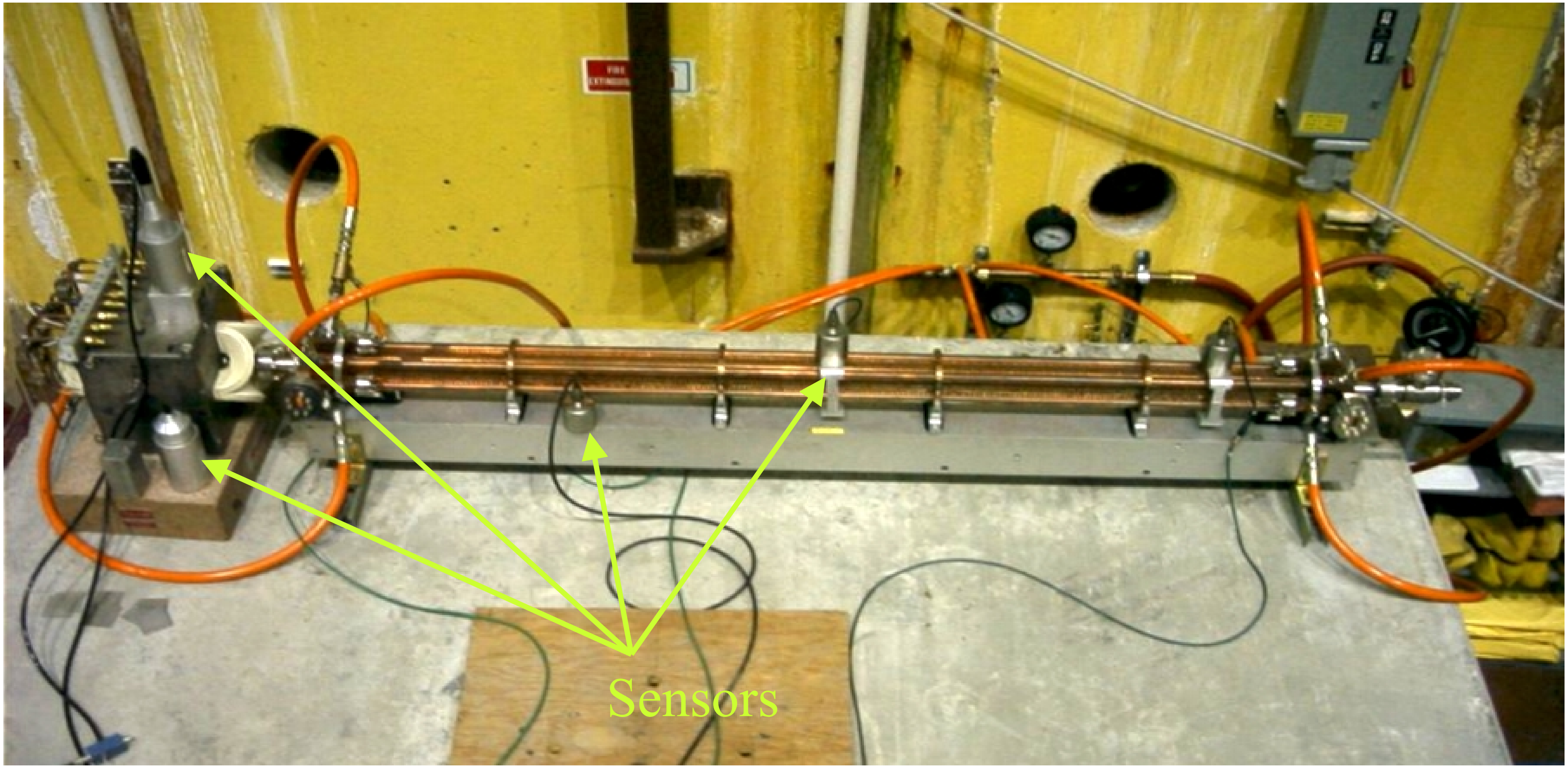
- Study vibration transmission to quadrupole in a structure-quad assembly



SLD pit. Gravity fed experiment

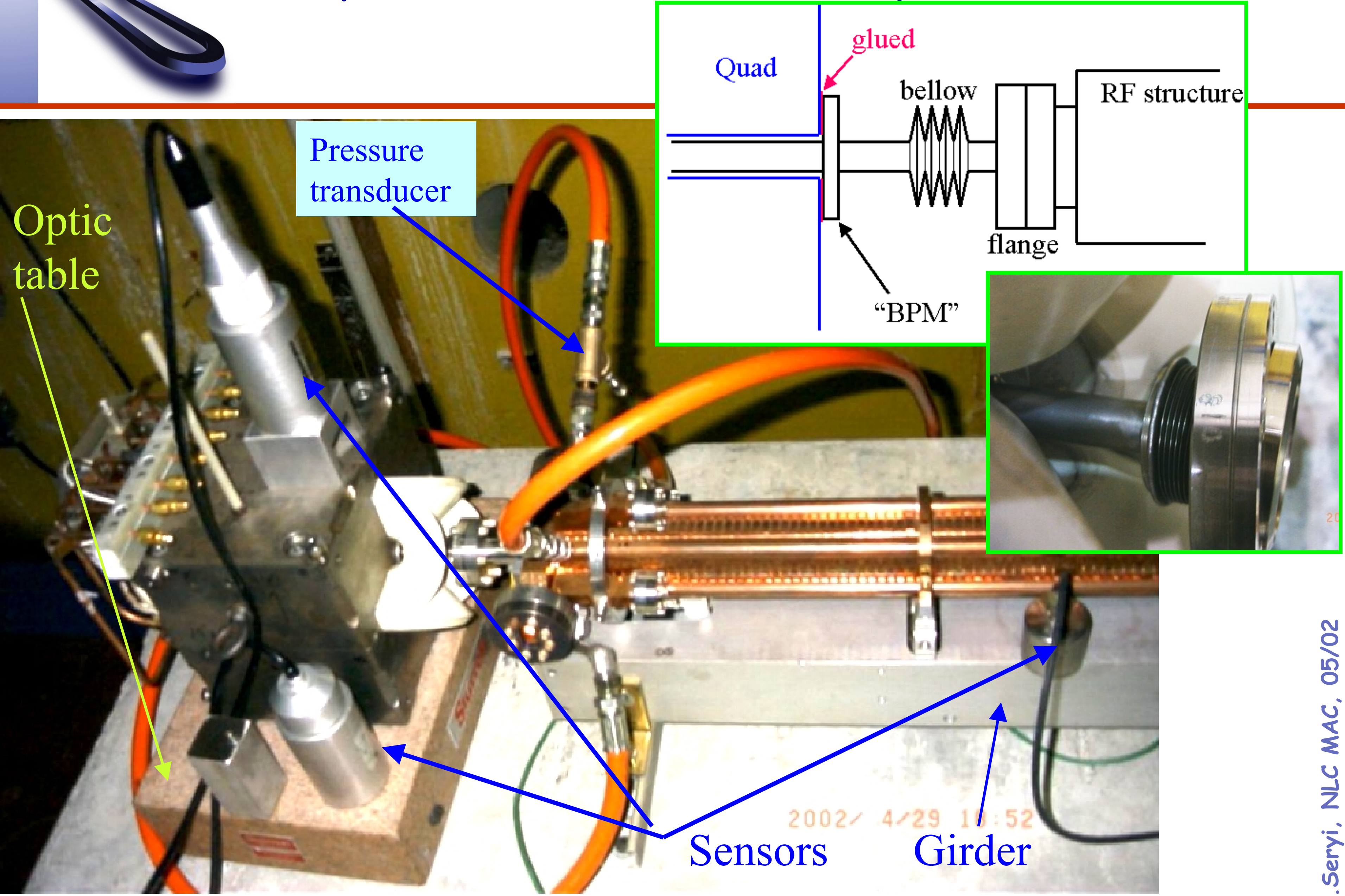


Quadrupole and RF structure setup in SLD pit

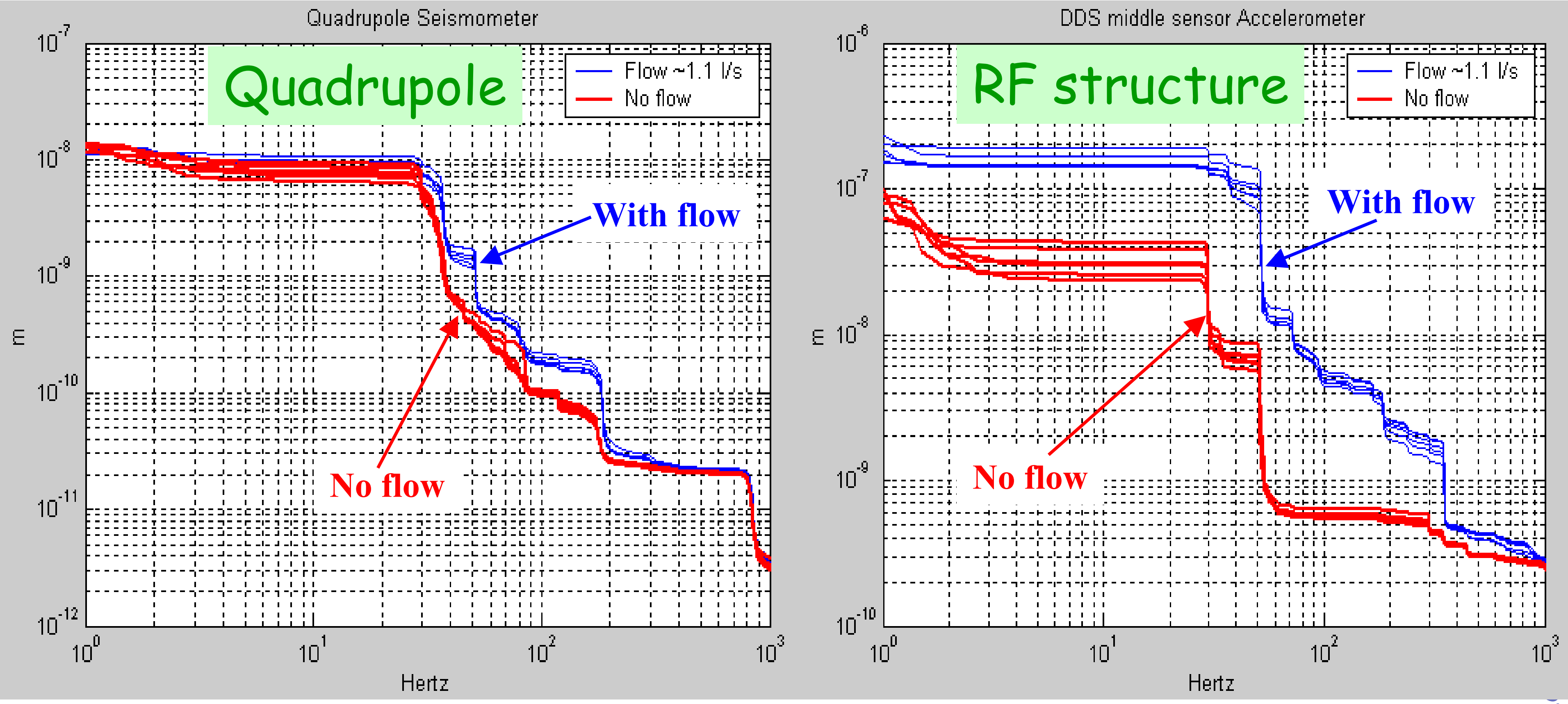


- Gravity fed water in the RF structure
- No water in quadrupole

Quadrupole and RF structure assembly and sensors

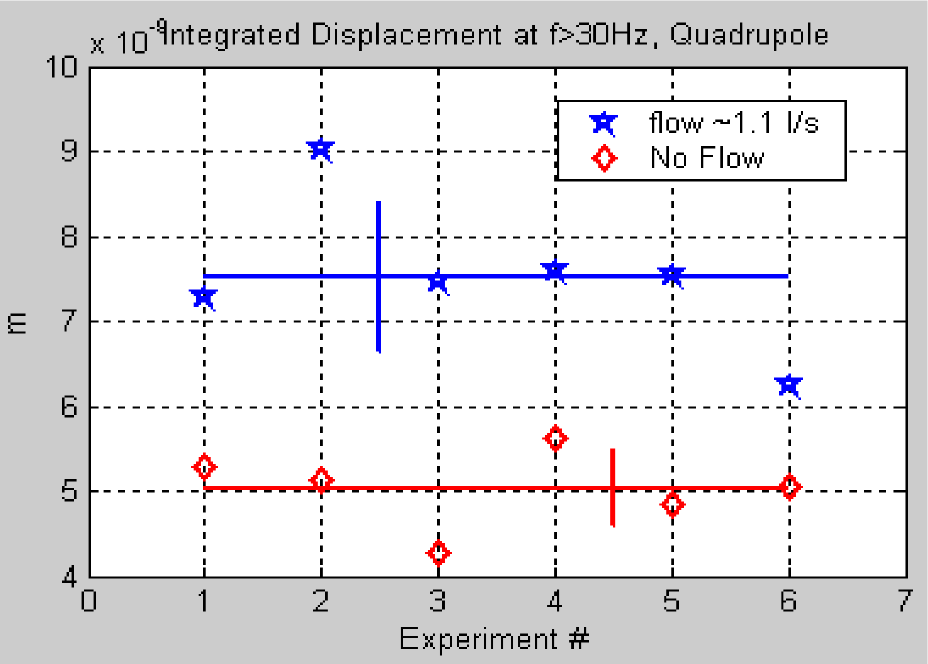


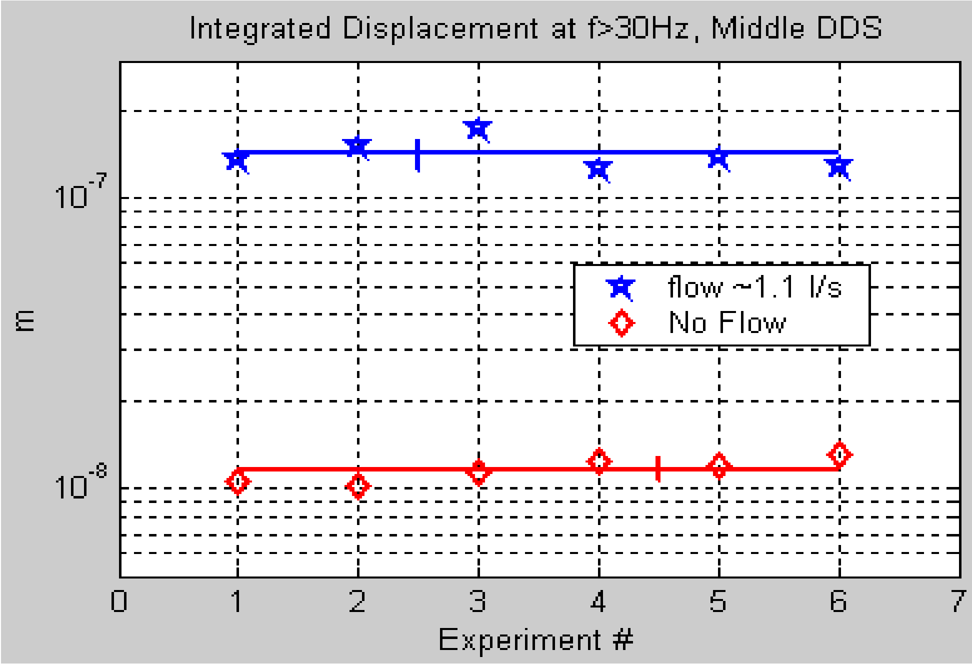
RF structure and Quad vibration in gravity fed case



- RF structure vibrates ~180nm (twice less then in NLCTA)
- **Several nm** of vibration **penetrates to the quadrupole**

RF structure to Quad vibration coupling in gravity fed case





180nm of RF structure vibration cause 5.6nm of quadrupole vibration *

The present mock-up is mechanically simplified. Actual NLC mechanical properties should be modeled and this may change the result.

* Assuming additional vibration is uncorrelated : $(7.5^2 - 5^2)^{\frac{1}{2}} = 5.6$nm

Simplifications in the present RF structure – quad mock up

- No vacuum, the bellow may become more rigid when pumped out
- Girder is tied to concrete at the end points, and no movers under the girder
- Quad placed on shims – need to place on mover-like device
- Girder is not of the right length
- Gravity fed water is more quiet

Reality can make it worse (or better?)

- Overall design can certainly be improved to increase damping and avoid high Q resonances

Better design can improve it

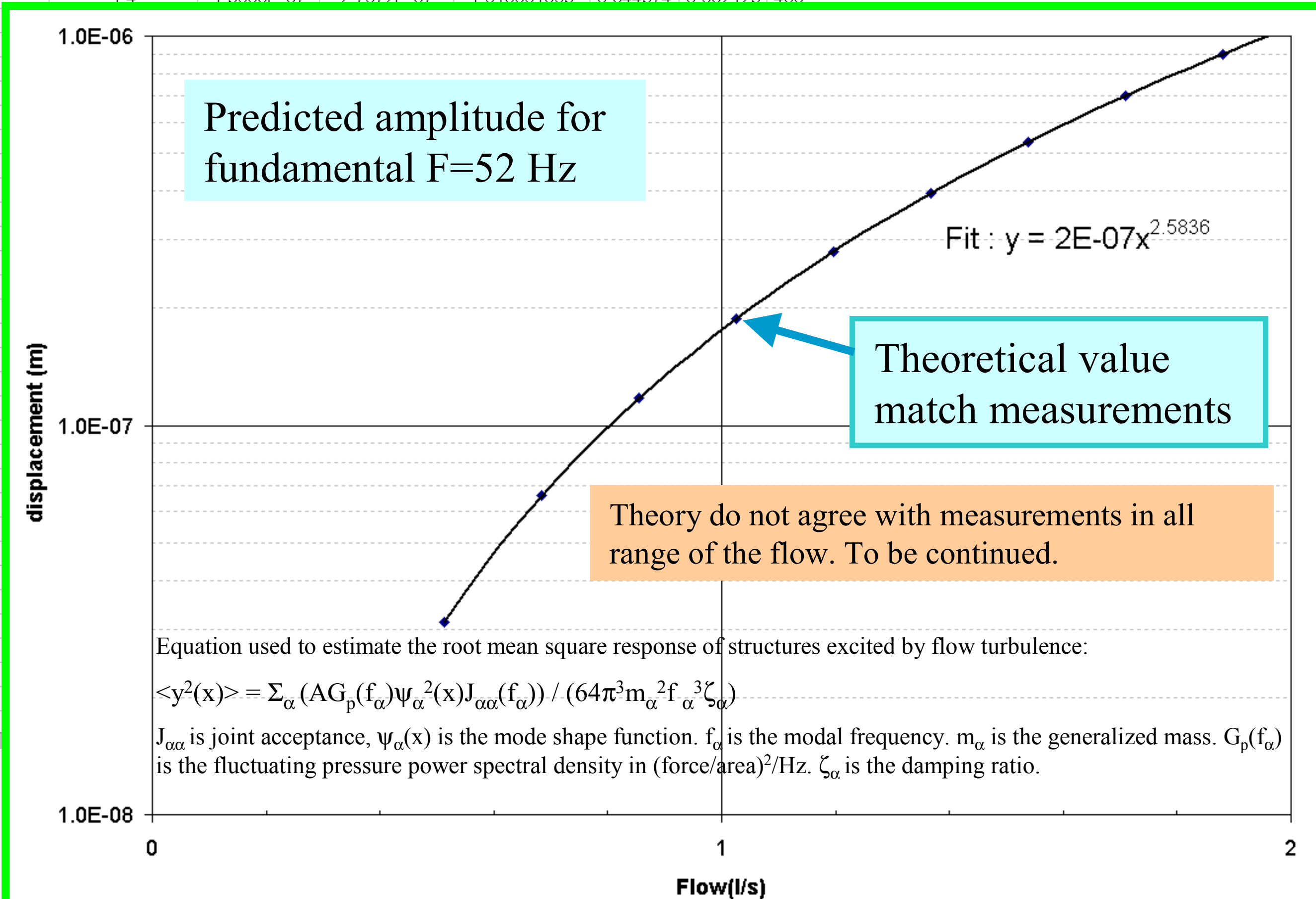
Theoretical estimations of turbulence induced vibrations (Sri Adiga)

	A	B	C	D	E	F	G	H	I	
1	Spreadsheet analysis of velocities on vibration induced									
2										
3			Velocities (l/s)	Velocities (m/s)	Vibration	Total Vibration	2*pi*H_r*f/v	Uc/V	Uc	4fL
4			0.512919	**0.6**	1.56671E-08	3.13342E-08	4.477645791	0.595577	0.357346	103
5	frequency	Hydraulic Radius	0.683892	**0.8**	3.29443E-08	6.58887E-08	3.358234343	0.605104	0.484083	761
6	51.85461252	0.00825	0.854865	1	5.86351E-08	1.1727E-07	2.686587475	0.61746	0.61746	597
7			1.025838	1.2	9.3914E-08	1.87828E-07	2.238822896	0.630904	0.757085	487
8	**Length**	**Density of Fluid**	1.196811	1.4	1.3986E-07	2.7972E-07	1.918991053	0.644374	0.902123	408
9	1.778	1000	1.367784							
10			1.538757							
11	**Inner Diameter**	**Density of material**	1.70973							
12	0.0165	8230	1.880703							
13			2.051676							
14	**Outer Diameter**	mode shape function	2.222649							
15	0.025	1.060593887	2.393622							
16			2.564595							
17	Moment of Inertia	**no. of pipes**	2.735568							
18	1.55285E-08	4	2.906541							
19			3.077514							
20	**Young's Modulus**		3.248487							
21	1.75E+12		3.41946							
22			3.590433							
23	Mass per Unit Length		3.761406							
24	2.492675263		3.932379							
25			4.103352							
26	**no. of supports**		4.274325							
27	2		4.445298							
28			4.616271							
29			4.787244							
30	**All Bold values must be entered**		4.958217							
31			5.12919							
32	**Critical Velocity(m/s**	**Critical Velocity(l/s)**	5.300163							
33	629.7428205	538.3450963	5.471136							
34			5.642109							
35	Critical Velocity is that velocity		5.813082							
36	beyond which the pipe buckles		5.984055							
37			6.155028							
38			6.326001							

Chrt_1tube | 1tube simul | Sheet3 | Chrt_4tube | 4tube simul

Young's modulus adjusted to match F to be 52Hz

Simulations of structure-girder system supported at each end



Preliminary evaluation for cooling induced vibration (nominal flow)

- RF structure vibration:
  - About 180nm if fed with quiet water
  - About 350nm mostly due to turbulence in supplying pipes for water system similar as in NLCTA
- EM quad receive
  - About 5.6nm due to coupling to structure if structure fed with quiet water
  - About 10.8nm *estimated* from coupling to structure (due to turbulence in supplying pipes in NLCTA like system)
  - About 3.3nm due to EM quad cooling
- Total vibration (if all sources are independent) for EM quad with NLCTA-like water system:

$$(3.3^2 + 10.8^2)^{\frac{1}{2}} = 11\text{nm} \pm$$ all "if" , all simplifications and difference to real system

* 10nm in linac gives about 0.25sigmaY at IP

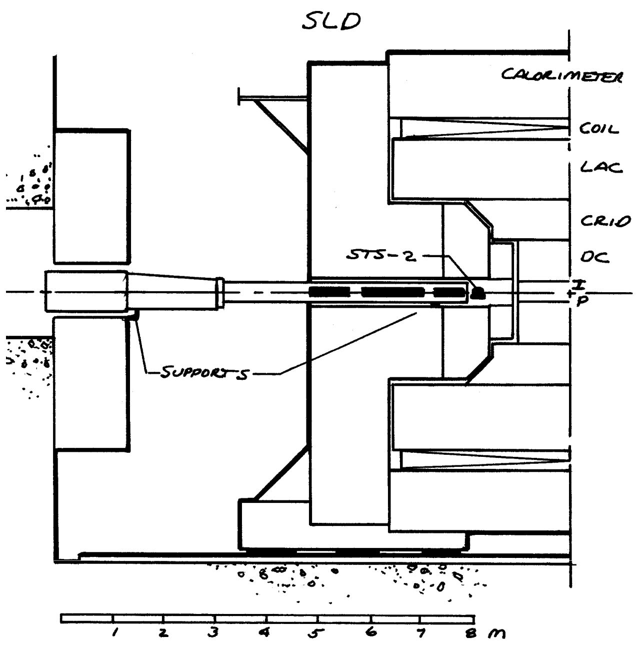
Rough (&incomplete) tolerances for in-tunnel added motion

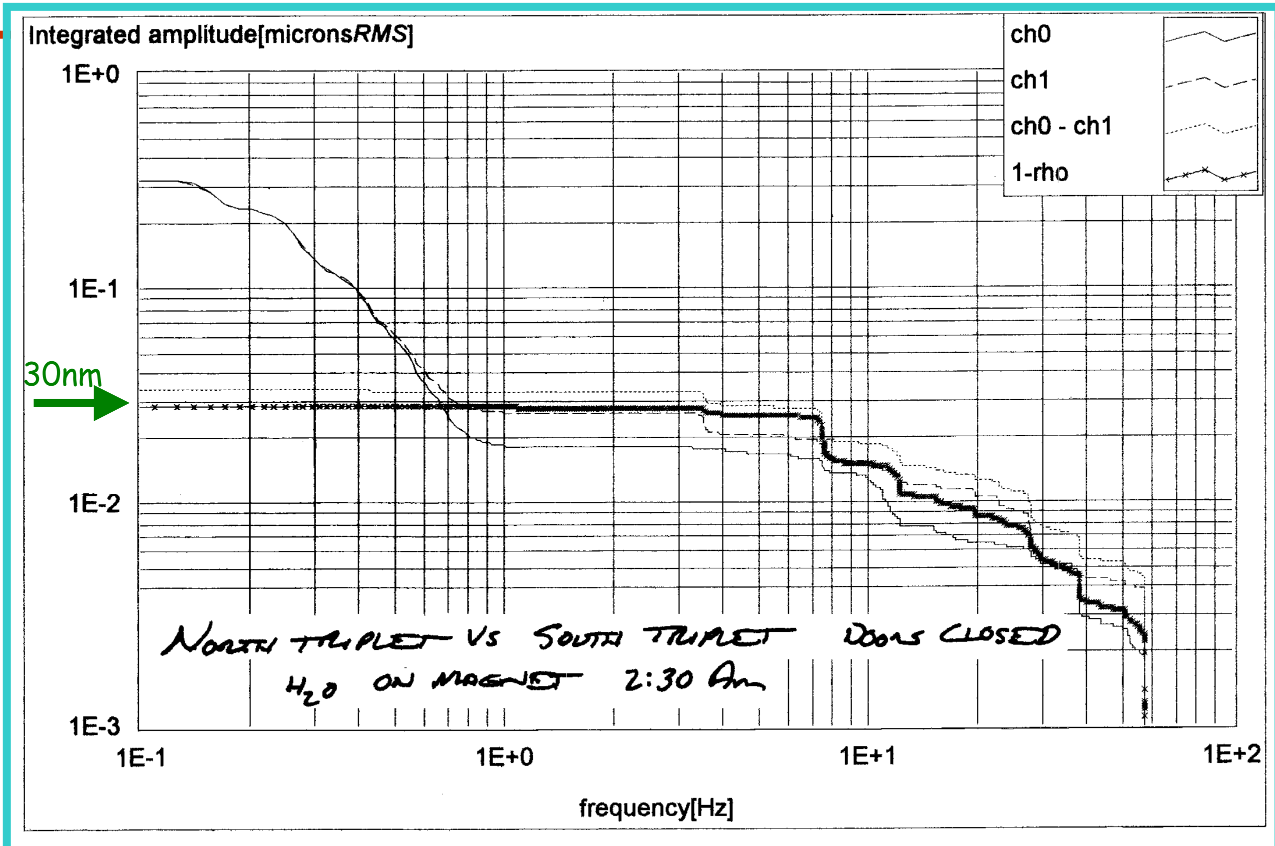
- In a site similar to SLAC at 2am, added fast motion not to exceed 3nm for > 3Hz
  - => Set specs for equipment

- Added slow diffusive motion not to exceed 3µm over 100m after one day
  - => set specs for T° stability etc.

Cultural noise at detector

1995 SLD measurements [Gordon Bowden]

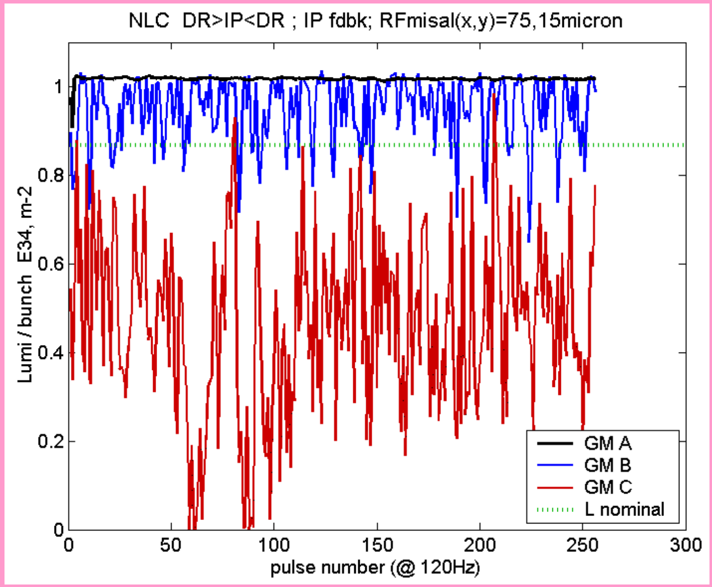




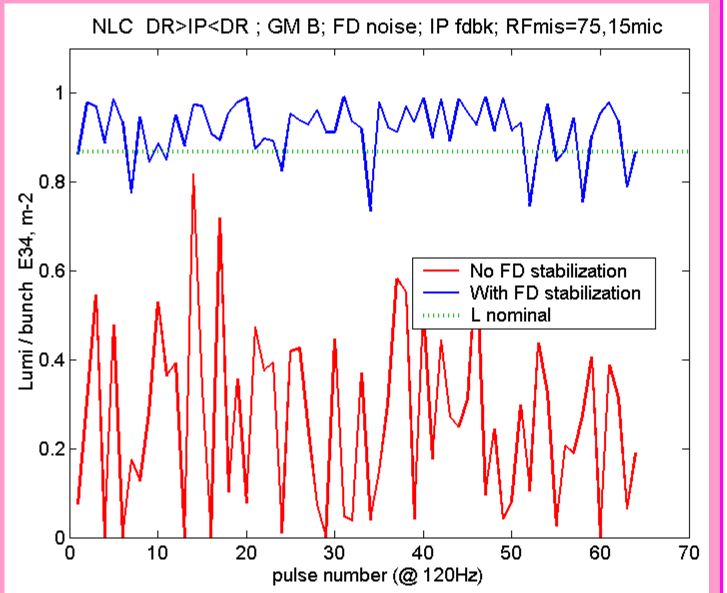
- Measured ~30nm relative motion between South and North final triplets
  - Magnetic field was OFF (magnetic field ON could have increases detector rigidity)
  - North triplet (Ch1) noisier – this side of the building is closer to ventilation and compressor stations
  - Resonances (3.5Hz, 7Hz) are likely to be resonances of detector structure
- More quiet detector possible, but at what cost and how much more quiet ?

Linac and IP stability

- Conditions, at which NLC would reliably work, are achievable
- However, it would not happen automatically
- Development and optimization of hardware takes time
- R&D should be vigilantly pursued, to provide both linac and IP stability



Simulation of entire NLC (e- and e+) with ground motion, RF structure misalignment and IP feedback. The FD are locked to the ground.



NLC with GM B, IP feedback and additional 20nm noise at each FD. Stabilization represented by an idealized transfer function.

Joint efforts of many people

BINP - slow and fast motion studies
Andrei Chupira, Alexander Erokhin Anatoly Medvedko, Mikhail Kondaurov, Vasili Parkhomchuk, Shavkat Singatulin, Evgeny Shubin

BNL - vibration propagation analysis
Nick Simos

CERN - FD stabilization collaboration, etc.
Ralph Assmann, Stefano Redaelli

FNAL - slow and fast motion studies, girder stability, etc.
Joe Lach, Chris Laughton, Duane Plant, Vladimir Shiltsev

Northwestern University - NUMI tunnel studies, stabilization
Mayda Velasco, Heidi Shellman, Inanc Birol, Gokhan Unel

Oxford University - super fast feedback for IP
Phil Burrows, Simon Jolly, Gerald Myatt, Gavin Nesom, Colin Perry, Glen White

SLAC - slow and fast motion, cultural noises, stabilization, etc.
Chris Adolphsen, Fred Asiri, Gordon Bowden, Marty Breidenbach, John Cogan, Carlos Damian, Eric Doyle, Leif Eriksson, Joe Frisch, Linda Hendrickson, Tom Himel, Frederic Le Pimpec, Tom Markiewicz, Rainer Pitthan, Tor Raubenheimer, Robert Ruland, Andrei Seryi, Steve Smith, Peter Tenenbaum, Mike Woods, Nancy Yu

Stanford University - turbulence induced vibration analysis
Sri Adiga

University of British Columbia - optical anchor development
Tom Mattison, Russ Greenall, Parry Fung

et al.

Summary

- In this talk, you have been updated on:
  - Current studies of ground motion
  - Preparation for studies in NUMI
  - Discussion on the proposal to study two tunnel vibration propagation
  - Slow motion studies at FNAL and SLAC
  - RF structure and linac quad stability study
  - Detector cultural noise